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GEOENGINEERING: THE ETHICAL AND SOCIAL ISSUES

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Doutoramento no ramo de Filosofia, especialidade de Filosofia da Natureza e do Ambiente

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Tese orientada pelo Professor Doutor Viriato Soromenho-Marques e pela Doutora Ângela Guimarães Pereira no âmbito do Programa Doutoral em Alterações Climáticas e Políticas de Desenvolvimento Sustentável

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European
Commission

To Elisa Maria

RESUMO

Desde a entrada em vigor, em 1994, da Convenção Quadro das Nações Unidas para as Alterações Climáticas (CQNUAC), proposta inicialmente na Conferência das Nações Unidas sobre Ambiente e Desenvolvimento (Rio de Janeiro, 1992), as respostas ao problema das alterações climáticas surgem associadas a dois grandes grupos de estratégias:

- políticas e medidas de mitigação, que visam eliminar as causas antropogénicas das alterações climáticas através da redução da emissão de gases com efeito de estufa para a atmosfera, e
- políticas e medidas de adaptação, que englobam quaisquer ajustamentos nos sistemas humanos e/ou naturais, em resposta a estímulos climáticos observados ou expectáveis, com o objectivo de minimizar os efeitos negativos ou explorar oportunidades benéficas.

Contudo, uma estratégia alternativa para fazer face ao problema das alterações climáticas tem vindo a ganhar terreno ao longo da última década: a *Geoengenharia* (ou *Engenharia Climática*), comummente definida como a "manipulação deliberada e em larga escala do ambiente planetário para combater as alterações climáticas antropogénicas" (The Royal Society 2009: 1). Embora o termo geoengenharia surja associado a um conjunto vasto de tecnologias - que comportam modos de actuação distintos e riscos e efeitos secundários diversos - duas grandes categorias de métodos procuram abarcar o conjunto de tecnologias até à data propostos: Remoção do Dióxido de Carbono e Gestão da Radiação Solar (CDR e SRM, respectivamente, nas siglas em inglês). Como o nome indica, os métodos de remoção do dióxido de carbono visam reduzir as concentrações de dióxido carbono na atmosfera e, deste modo, contribuir para o arrefecimento do sistema Terra-atmosfera através da redução da quantidade de radiação de longo comprimento de onda emitida pela superfície terrestre (radiação

térmica infravermelha) que é absorvida pela atmosfera. O segundo conjunto de métodos, gestão da radiação solar, visa igualmente alterar o balanço radiativo da Terra, mas através do aumento da quantidade de radiação solar incidente que é reflectida para o espaço - gerando assim um aumento do albedo planetário que concorre para uma diminuição da temperatura.

Até recentemente, a comunidade científica olhava para estas propostas com cepticismo, se não mesmo com incredulidade. De facto, em 2007, o Painel Intergovernamental para as Alterações Climáticas (IPCC) ainda considerava que as soluções de geoengenharia - tais com a fertilização dos oceanos para promover a remoção de CO_2 da atmosfera, ou a colocação de materiais na alta atmosfera de modo a reduzir a quantidade de radiação solar recebida pela superfície terrestre - eram em larga medida especulativas, comportando riscos e efeitos secundários desconhecidos.

Porém, desde a publicação do Quarto Relatório de Avaliação do IPCC, a geoengenharia tem atraído uma atenção crescente no contexto das alterações climáticas, passando de um tópico discutido maioritariamente em ficção científica e artigos científicos esotéricos para o centro dos debates científico e político (Macnaghten and Szerszynski 2013: 465). As tentativas fracassadas de redução das emissões globais de gases com efeito de estufa (Crutzen 2006) — um sintoma do que tem sido descrito como um “problema de inércia política” (Gardiner 2010: 286-287) — o apelo cada vez mais intenso para uma maior gestão planetária (Global Environmental Change Programmes 2001) e a tendência para valorizar as respostas às alterações climáticas de natureza transformacional em detrimento das de natureza incremental (New *et al.* 2010) são alguns dos factores que ajudam a explicar a razão pela qual o cepticismo e a desconfiança com que a geoengenharia foi inicialmente acolhida deram lugar a uma ponderação mais pragmática e séria dos seus recentes avanços científicos e tecnológicos.

No entanto, o conhecimento científico associado aos processos de geoengenharia climática é bastante limitado, existindo inúmeras incertezas acerca dos impactos potenciais destas tecnologias nos sistemas humanos e naturais. O modo como os métodos de geoengenharia visam alterar forçamentos à escala planetária, a imprevisibilidade dos impactos das acções de geoengenharia nos diferentes subsistemas climáticos e as enormes incertezas associadas a estes métodos revelam uma mudança na natureza da acção humana que pressupõe uma ética, assente na responsabilidade e antecipação, capaz de fazer face à escala e complexidade das enormes tarefas tecnocientíficas envolvidas. De facto, antes de se considerar a possibilidade de embarcar em tão ambicioso projecto, um esforço considerável deverá ser realizado no sentido de escrutinar e aprofundar as implicações éticas e sociais da geoengenharia.

Deste modo, o principal objectivo desta dissertação é o de contribuir para uma melhor compreensão das implicações éticas e sociais associadas às recentes propostas de geoengenharia e, com esse propósito, encontrar um ponto de vista adequado para responder às seguintes questões:

- Porque razão é hoje a geoengenharia considerada uma resposta possível às alterações climáticas antropogénicas?
- Que “imaginários” de ciência e tecnologia subjazem aos debates em torno da geoengenharia?
- Quão plausíveis são as actuais propostas de geoengenharia climática?
- Quais são as expectativas, os valores e os modos de construção de sentido contidos nas propostas de geoengenharia?
- Que tipo de enquadramento ético poderá servir de base à análise das propostas de geoengenharia e apoiar os processos de tomada de decisão política?

A dissertação está organizada em duas partes. A primeira parte inclui os capítulos de 1 a 5. No primeiro capítulo são apresentados os objectivos e as questões que guiaram esta investigação, bem como alguns dos pressupostos e premissas iniciais. No segundo capítulo é descrita a abordagem metodológica e discutidas as opções que determinaram o conjunto de métodos de análise adoptados. O capítulo 3 inclui a descrição do problema em análise, uma breve apresentação dos principais métodos de geoengenharia propostos e a discussão acerca da relevância do estudo dos aspectos éticos e sociais associados a estas propostas. Os principais resultados desta investigação surgem sumariados no capítulo 4, organizado em torno das cinco questões que guiaram esta dissertação. Finalmente, no capítulo 5 são apresentadas as principais conclusões e linhas de investigação a explorar no futuro.

A parte II da dissertação reúne o conjunto de artigos escritos no decorrer desta investigação.

ABSTRACT

Since the adoption of the United Nations Framework Convention on Climate Change (UNFCCC), responses to address climate change have fallen within two major groups of strategies, namely:

- mitigation measures, which comprise all human interventions to reduce the anthropogenic forcing of the climate system, such as reducing greenhouse gas sources and emissions and enhancing greenhouse gas sinks, and
- adaptation measures, which include any adjustments made to natural or human systems in response to actual or expected impacts of climate change, with the aim of moderating harm or exploiting beneficial opportunities.

However, another strategy to limit the impacts and consequences of climate change has been gaining ground over the past decade: the idea of geoengineering, commonly defined as the "*deliberate large-scale manipulation of the planetary environment to counteract anthropogenic climate change*" (The Royal Society, 2009: 1).

The self-assertive invasion of nature's various domains, the scale and complexity of the technoscientific tasks involved, the unpredictable long-term impacts of geoengineering actions, and the huge uncertainties that these proposals raise point to a shift in the nature of human action that requires a commensurate ethics of foresight and responsibility.

Through this dissertation I hope to offer a perspective from which the very nature of geoengineering proposals can be brought into question, so as to better focus on and deal with the fundamental issues that geoengineering proposals entail. Accordingly, the aim of this dissertation is to contribute to a better understanding of the far-reaching ethical and social implications of these proposals and, to that end, find an adequate vantage point from which to address the following research questions:

- Why is geoengineering becoming a part of the portfolio of response options to anthropogenic climate change?
- What ‘imaginaries’ of science and technology underlie geoengineering debates?
- How plausible are current geoengineering proposals?
- What are the expectations, the embedded values, and the ways of making sense of a geoengineered world?
- What kind of ethical framework can serve as a basis for assessing geoengineering proposals and inform policy responses to geoengineering governance?

LIST OF PUBLICATIONS

This dissertation is based on the following publications, which will be referred to in the text by their Roman numerals:

PAPER I - Curvelo, Paula and Guimarães Pereira, Ângela (2013). Geoengineering: reflections on current debates. *The International Journal of Science in Society*, Volume 4, Issue 3, pp. 1-21.

PAPER II - Curvelo, Paula (2012). Exploring the Ethics of Geoengineering through Images. *The International Journal of The Image*, Volume 2, Issue 2, pp. 177-198.

PAPER III - Curvelo, Paula (2013). Questioning the Geoengineering Scientific Worldview. *The International Journal of Interdisciplinary Environmental Studies* no. 7 (1):35-53.

PAPER IV - Curvelo, Paula (2013). Towards an Analytical Framework for Evaluating the Ethical Dimensions of Geoengineering Proposals. *The International Journal of Climate Change: Impacts and Responses*, volume 4, Issue 4, pp. 191-208

PAPER V - Curvelo, Paula (2013). Imag[in]ing geoengineering – the plausible and the implausible, *International Journal of Foresight and Innovation Policy*, Vol. 9, Nos. 2/3/4, pp. 162–187.

PAPER VI - Curvelo, Paula (forthcoming). Chapter 7 - Geoengineering Dreams, *in* Â. Guimarães Pereira and S. Funtowicz (Eds.) *Science, Philosophy and Sustainability: The End of the Cartesian Dream*. Routledge.

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Deepest thanks also go to all participants in the geoengineering threat of the University of British Columbia's online course "Climate Literacy: Navigating Climate Change Conversation" (Coursera, May-August 2013), particularly to Doris Miller and William Everett for their very insightful and thought-provoking posts.

I gratefully acknowledge the insightful comments and enthusiastic response received from anonymous reviewers who have helped me to rethink and reformulate my ideas. I nonetheless retain full responsibility for any errors, omissions, or inconsistencies that may remain.

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LIST OF USED ABBREVIATIONS

AOGCMs	Atmosphere–Ocean General Circulation Models
AR4	IPCC Fourth Assessment Report
AR5	IPCC Fifth Assessment Report
BECCS	Bio-energy combined with carbon capture and storage
CE	Climate Engineering
CCN	Cloud Condensation Nuclei
CCS	Carbon Capture and Storage
CDR	Carbone Dioxide Removal
DAC	Direct Air Capture
GHG	Greenhouse Gas
GMST	Global Mean Surface Temperature
IPCC	Intergovernmental Panel on Climate Change
LULCC	Land-Use and Land-Cover Change
NPP	Net Primary Productivity
OIF	Ocean Iron Fertilisation
RCP	Representative Concentration Pathways
RF	Radiative Forcing
SRM	Solar Radiation Management
UNCLOS	United Nations Convention on the Law of the Sea
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
WMO	World Meteorological Organisation

UNITS OF MEASURE

PgC yr^{-1}	Petagram of carbon per year
ppb	Parts per billion
ppm	Parts per million
W m^{-2}	Watts per square metre

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PART I

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1. INTRODUCTION

> "*A risk management strategy for climate change will require integrating responses in mitigation with different time horizons, adaptation to an array of climate impacts, and even possible emergency responses such as 'geoengineering' in the face of extreme climate impacts. In the face of potential extreme impacts, the ability to quickly offset warming could help limit some of the most extreme climate impacts although deploying these geoengineering systems could create many other risks*" (IPCC, 2014b: 9).

Since the adoption of the United Nations Framework Convention on Climate Change (UNFCCC), responses to address climate change have fallen within two major groups of strategies, namely:

- mitigation measures, which comprise all human interventions to reduce the anthropogenic forcing of the climate system, such as reducing greenhouse gas sources and emissions and enhancing greenhouse gas sinks, and
- adaptation measures, which include any adjustments made to natural or human systems in response to actual or expected impacts of climate change, with the aim of moderating harm or exploiting beneficial opportunities.

However, another strategy to limit the impacts and consequences of climate change has been gaining ground over the past decade: the idea of geoengineering, commonly defined as the "deliberate large-scale manipulation of the planetary environment to counteract anthropogenic climate change" (The Royal Society, 2009: 1).

Hitherto, the scientific community has regarded these proposals with scepticism, if not outright disbelief (Cicerone, 2006; Wolpert, 2008; Fleming, 2010). Indeed, in 2007 the Intergovernmental Panel on Climate Change (IPCC) still considered that "geo-engineering options, such as ocean fertilisation to remove CO_2 directly from the atmosphere, or blocking sunlight by bringing material into the upper atmosphere, remain largely speculative and unproven, and with the risk of unknown side-effects" (IPCC, 2007: 15, emphasis added).

Since the publication of the AR4, geoengineering has attracted increasing attention as a means to address climate change, having been "transformed from a topic discussed largely in science fiction and esoteric scientific papers into mainstream scientific and policy debate" (Macnaghten and Szerszynski, 2013: 465). The "grossly unsuccessful" efforts to lower carbon dioxide emissions (Crutzen, 2006) — a symptom of what has been described as a "problem of political inertia" (Gardiner, 2010: 286-287) — the resonant call for greater planetary management and Earth-system control (Global Environmental Change Programmes, 2001), and the tendency to favour transformational rather than incremental responses to climate change (New et al., 2010) are all factors that may help explain why the scepticism and suspicion with which geoengineering was initially greeted is now giving way to a more pragmatic and serious consideration of its latest scientific and technological breakthroughs and the challenges ahead.

However, the understanding of the physical science basis of geoengineering is still limited, and there are still major uncertainties concerning the impacts these technologies might have on human and natural systems. The self-assertive invasion of nature's various domains, the scale and complexity of the technoscientific tasks involved, the unpredictable long-term impacts of geoengineering actions, and the huge uncertainties that these proposals raise point to a shift in the nature of human action that requires a commensurate ethics of foresight and responsibility. If there is a decision to embark on such an ambitious project, a major effort should be made to scrutinise and gain a deeper understanding of the social and ethical implications of geoengineering.

1.1 Aim and research questions

In the prologue to her book *The Human Condition*, Hannah Arendt (1958) refers to the launch of the first artificial satellite in 1957 and recalls the line carved on the funeral obelisk of the Russian scientist Konstantin E. Tsiolkovsky – "Mankind will not remain bound to the earth forever” – to illustrate the human capacity for making new beginnings and to reflect about the meaning of this first "step toward escape from men's imprisonment to the earth" *(Idem*: 1). For Arendt, the launch of Sputnik 1 is fraught with both historical and symbolic significance. It represents the first step towards realising the hubristic desire of "liberating" us from Earth - the very quintessence of the human condition. The same desire, Arendt believes, manifested in the attempt to create life in the test tube, and thus "cutting the last tie through which even man belongs among the children of nature" (*Idem*: 2).

This desire long precedes our knowledge, showing “that men everywhere are by no means slow to catch up and adjust to scientific discoveries and technical developments (...) Here, as in other respects, science has realized and affirmed what men anticipated in dreams that were neither wild nor idle” (*Idem Ibidem*). With this passage Arendt not only makes the case for the need to resist a deterministic view of the autonomy of science and technology, but also paves the way to a central discussion in (of) *The Human Condition*: the Earth alienation underlying the whole development of natural science in the modern age.

> "This future man, whom the scientists tell us they will produce in no more than a hundred years, seems to be possessed by a rebellion against human existence as it has been given, a free gift from nowhere (secularly speaking), which he wishes to exchange, as it were, for something he has made himself. There is no reason to doubt our abilities to accomplish such an exchange, just as there is no reason to doubt our present ability to destroy all organic life on earth. The question is only whether we wish to use our new scientific and technical knowledge in this direction, and this question cannot be decided by scientific means; it is a political question of the first order and therefore can hardly be left to the decision of professional scientists or professional politicians" (*Idem*: 2-3).

It is with this question in mind - *whether we wish to use our new scientific and technical knowledge in this direction* - that I propose to examine current proposals to intentionally engineer the Earth’s climate. Motivated by a conviction that we need to move beyond the rhetoric of risk, fear, and control, which provides justification to geoengineering proposals within a "risk management strategy for climate change" (IPCC, op. cit), I take this question as the fundamental question that needs to be answered before we decide whether geoengineering should indeed be considered as a *possible emergency response to climate change*. Moreover, by recognising that this fundamental question (and concomitant ones concerning geoengineering research, governance and deployment) *is a political question of the first order, that* cannot be decided by scientific means or left to *the decision of professional scientists or professional politicians,* I take as the point of departure for the present research the need to open up the discussion around geoengineering and to subject it to greater critical scrutiny. Thus, through this dissertation I hope to offer a perspective from which the very nature of geoengineering proposals can be brought into question, so as to better focus on and deal with the fundamental issues that geoengineering proposals entail. Accordingly, the aim of this dissertation is to contribute to a better understanding of the far-reaching ethical and social implications of these proposals and, to that end, find an adequate vantage point from which to address the following research questions:

- Why is geoengineering becoming a part of the portfolio of response options to anthropogenic climate change?
- What 'imaginaries' of science and technology underlie geoengineering debates?
- How plausible are current geoengineering proposals?
- What are the expectations, the embedded values, and the ways of making sense of a geoengineered world?
- What kind of ethical framework can serve as a basis for assessing geoengineering proposals and inform policy responses to geoengineering governance?

The formulation of these questions is intended to highlight the need to unlock the geoengineering debate from the path-dependent questions that, almost invariably, provide justification for more and more research. Thus, it takes the standpoint that scientific enterprise is not merely a matter of epistemic permissibility, but also of moral permissibility. An enterprise that entails methodological choices of perspective − "What is to be studied, by what means, for what purpose?" (Strand, 2002: 172) −, which cannot be excused from moral considerations and cannot be thought of as something entirely outside the realm of action.

> "We have to choose what we want to know, imposing a context; research per se often irreversibly changes the world through its invention of technology; and the course of this development is not inevitable, but has a historical character" (*Idem Ibidem*).

Therefore, these research questions demarcate themselves from the technically feasible and cost-effective responses that, within a utilitarian framework, have been advanced in the geoengineering debate, suggesting that only within the development of a systematic discourse, involving ethics − as accompanying research ('Begleitforschung') (Hronszky, 2005) − can a better understanding of the ethical and social implications of geoengineering be achieved.

1.2 Dissertation outline and content

This dissertation is organised in two parts. Part I comprises this introductory chapter and chapters 2 to 5. Chapter 2 briefly describes how the literature survey was carried out and the methodological approach taken. It introduces the main features and assumptions of discourse analysis within the general field of social constructivism and presents the relevance of discourse analysis to address the research questions identified in Chapter 1. Chapter 3 outlines the background of this research and defines the problem under analysis. In doing so, it highlights the uncertainties and controversies surrounding geoengineering and the significance of this research. Chapter 4 presents a brief summary of each paper and discusses the main findings of this dissertation. Finally, chapter 5 concludes with a summary of open questions and areas for further research.

Part II of the dissertation includes all the articles published in peer-reviewed journals, as well as a chapter for publication in the book "*Science, Philosophy and Sustainability: The End of the Cartesian Dream*".

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2. METHODOLOGY

> "*Although discourse analysis can be applied to all areas of research, it cannot be used with all kinds of theoretical framework. Crucially, it is not to be used as a method of analysis detached from its theoretical and methodological foundations. (...) In discourse analysis, theory and method are intertwined and researchers must accept the basic philosophical premises in order to use discourse analysis as their method of empirical study*" (Jorgensen and Phillips, 2002: 3-4).

In this chapter I present the methods used to conduct this dissertation. I begin with a brief description of the primary sources of information and the literature survey conducted in the initial stages of the project. This section is followed by a description and justification of the methods of discourse analysis used to address the research questions identified in the previous chapter.

2.1 Literature survey and sources of information

Given the exploratory nature of my research questions, I began this research by carrying out an extensive literature survey in order to gain a better understanding of the current debates on geoengineering (**PAPER I**). The initial literature survey was carried out from September 2010 to January 2011 using multiple databases: Thomson's Web of Science, Scopus (Elsevier), JSToR, Academic Search (Ebsco), and Ingentaconnect. The search was performed using the following combination of terms "geoengineering" OR "climate engineering" OR "solar radiation management" OR "carbon dioxide removal" in the title, abstract or keywords of the article. Articles published in all years were considered. References cited in the retrieved publications were also reviewed. Using Google Scholar and further web engines the literature survey was finally extended to include grey literature, media news, films, blog comments, and all kinds of visual representations of geoengineering.

Over the past three years the field of geoengineering has grown dramatically, and there is an accelerating trend in the number of media and scientific publications on this topic (Belter and Seidel, 2013), therefore the collection and review of relevant documentation was an on-going process and continued throughout the later stages of the project. Accordingly, and as illustrated by the attempt to take into consideration the recent assessment of geoengineering solutions conducted by the IPCC (cf. Chapter 3 and **Paper VI**), the literature review was revisited at several points of this research in order to keep the dissertation continuously updated and supplemented with the latest research findings in the field of geoengineering.

At the same time as this information was being gathered and analysed, I developed a website on geoengineering aimed to facilitate further research on this topic, as well as to provide a space for reflection and debate on the social and ethical implications of geoengineering[1]. A short movie produced in the context of the project Technolife[2] was included in the website in order to engage the public at large in the online debate on geoengineering. Through three fictional situations, the movie presents the main aspects of geoengineering technologies and raises important questions concerning:

- the uncertainties and experimental nature of geoengineering proposals;
- the conditions under which geoengineering might be deployed;
- the policy issues and governance of geoengineering technologies.

The website went online in December 2012 and has since been updated periodically with relevant information on this topic. The questionnaire and online debate provided empirical material for this research and will constitute the basis of further analysis (Chapter 5).

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[1] https://sites.google.com/site/geoengineeringdebate/.

[2] The TECHNOLIFE project sought to develop new frameworks for the early identification, characterization, and deliberation upon ethical issues arising from a broad range of information and communication technologies (ICTs), including their convergence with other scientific and technological fields (such as bio-nano). Providing multi-layered descriptions and normative analyses through inter-and trans-disciplinary research, the project worked to improve existing conceptual frameworks and procedures for implementing and representing the social needs and interests of citizens at early stages of policy-making and research. For more information on the Technolife Projects see: http://technolife.no/.

This study applies discourse analysis methods (narrative analysis and visual narrative analysis) to address the complexity of the broader scientific, political, and social context in which the geoengineering debate is taking place. In what follows, I briefly introduce the main theoretical assumptions of discourse analysis, thus providing the analytical framework which informed the methodological approach used to address the research questions presented in Chapter 1. Finally, I describe the two approaches to discourse analysis used in this dissertation and discuss their relevance to examine the plausibility of geoengineering, its objects of research, and the sociotechnical imaginaries that underpin current visions of a geoengineered world.

2.2 Science is discourse and fiction

In *Laboratory Life: The Social Construction of Scientific Facts*, Bruno Latour and Steve Woolgar (1986) traced the construction of scientific facts by examining the daily activities carried out in one particular neuroendocrinology laboratory[3]. The focus of their analysis was the social processes involved in the establishment of thyrotropin releasing factor (Hormone) as a "scientific fact"; an analysis motivated by their concern "with the social construction of scientific knowledge in so far as this draws attention to the process by which scientists make sense of their observations"[4].

Through the use of ethnographic-based discourse analysis Latour and Woolgar examined the "literary inscriptions"[5] used and produced by the scientists and technicians of the laboratory - "a strange tribe who spend the greatest part of their day coding, marking, altering, correcting, reading, and writing"[6] - to illuminate the roles of inscription

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[3] *Laboratory Life* is the product of the fieldwork conducted between October 1975 and August 1977 by Bruno Latour in the neuroendocrinology research laboratory of Roger Guillemin (who was later awarded the Nobel Prize) at the Salk Institute for Biological Studies in San Diego, California. The book was published in 1979 in co-authorship with the British sociologist Steve Woolgar.

[4] Idem: 32.

[5] Idem: 45.

[6] Idem: 49.

devices[7], discipline-scientific research procedures, and rhetorical strategies in the construction of "scientific facts".

By emphasising the processes whereby scientific facts are constructed as "literary inscriptions" and "statements" with no referent to an "independent existence out there" Latour and Woolgar argued that scientific work is largely a rhetorical and linguistic activity that involves both persuasion and making of meaning; a form of "literary production" conducted by "writers and readers in the business of being convinced and convincing others"[8] and which "comprises the construction and sustenance of fictional accounts[9] which are sometimes transformed into stabilised objects".

In making this case, Latour and Woolgar stressed the importance of refusing important distinctions commonly adopted both by historians and analysts of science: "the distinction between social and technical issues"; "the distinction of nature between facts and artefacts"; "the a priori distinction between commonsense and scientific reasoning"; "and even the distinction between 'thought' and craftwork needed to be avoided as an explanatory resource because it appeared to be the *consequence* of scientific work in the laboratory"[10].

By translating scientists' practice and experiments into discursive techniques Latour and Woolgar not only contributed to contemporary efforts in the humanities and social sciences to broaden the application of discourse analysis approaches to the study of scientific knowledge, but also brought to light the intricate and frequently ambiguous relation between discourse and praxis.

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[7] According to the authors "an inscription device is any item of apparatus or particular configuration of such items which can transform a material substance into a figure or diagram which is directly usable by one of the members of the office space" (Idem: 51).

[8] Idem: 88.

[9] In their attempt "towards making clear the link between science and literature" Latour and Woolgar incorporate a degree of reflexivity into their own analysis, reminding the reader that all texts are stories, and "that observers of scientific activity are engaged in methods which are essentially similar to those of the practioners which they study" (Idem: 30).

[10] Idem: 253.

It is in line with this notion of science, as discourse and fiction, that I suggest the relevance of adopting a "discursive framework" to critically analyse the documents and materials collected during the first stage of my research. All these documents and materials, despite their varied nature, are here considered as "literary inscriptions" of geoengineering, inasmuch as they seem to inform the diversity of framings of geoengineering and the way the field of geoengineering science is being defined and redefined.

As discussed in the following sections, the approaches to discourse analysis applied in this research were selected for their close attention to rhetorical forms of scientific argumentation. These approaches form the basis of my attempt to critically examine the "literary inscriptions" of geoengineering, i.e. the persuasive tools of a science-in-the-making that seems to have replaced the "laboratory ideal" by the "field ideal of experimentation" (Schwarz and Krohn, 2011), with all the consequences that this implies.

2.3 Discourse analysis

> "*Discourse has a quite specific meaning. It refers to groups of statements which structure the way a thing is thought, and the way we act on the basis of that thinking. In other words, discourse is a particular knowledge about the world which shapes how the world is understood and how things are done in it*" (Rose, 2001: 142).

Discourse analysis "focuses on talk and texts as social practices and on the resources that are drawn on to enable those practices" (Potter, 1996: 129). It encompasses a wide range of theoretical orientations and methodological approaches (Stubbs, 1983). As pointed out by Wood and Kroger, discourse analysis "is not only about method; it is also a perspective on the nature of language and its relationship to the central issues of the social science" (Wood and Kroger, 2000: x). Accordingly, discourse analysis can be seen as a set of collection of approaches to discourse that entail not only practices of data collection and analysis, but also a set of theoretical assumptions and key premises about how entities such as ‘language’ and ‘the subject’ are to be understood (Jorgensen and Phillips, 2002; Potter, 1996).

The general philosophical assumptions that underpin most discourse analytical approaches are found in social constructionism and were summarised by Gergen as follows:

> "The terms by which we account for the world and ourselves are not dictated by the stipulated objects of such accounts (...) The terms and forms by which we achieve understanding of the world and ourselves are social artifacts, products of historically and culturally situated interchanges among people (...) The degree to which a given account of world or self is sustained across time is not dependent on the objective validity of the account but on the vicissitudes of social process (...) Language derives its significance in human affairs from the way in which it functions within patterns of relationship (...) To appraise existing forms of discourse is to evaluate patterns of cultural life; such evaluations give voice to other cultural enclaves" (Gergen, 1994: 49-53).

In addition to these general social constructionist assumptions, all discourse analytical approaches share the following key premises with respect to their views of language and the subject (Jorgensen and Phillips, 2002: 12):

- Language is not a reflection of a pre-existing reality.
- Language is structured in patterns or discourses – there is not just one general system of meaning as in Saussurian structuralism but a series of systems or discourses, whereby meanings change from discourse to discourse.
- These discursive patterns are maintained and transformed in discursive practices.
- The maintenance and transformation of the patterns should therefore be explored through analysis of the specific contexts in which language is in action.

One form of discourse analysis that assumes particular significance in the context of this research is narrative analysis. Narrative analysis has been approached from many different angles across the social sciences and, depending on disciplinary priorities and research foci, a variety of analytical perspectives and methodologies have been proposed (Thornborrow, 2012: 51).

In this dissertation I draw upon the ideas of Rouse, who claimed that scientific research is intelligible only in the context of a narrative, and therefore narrative should occupy a fundamental place within our understanding of the sciences. Four crucial considerations inform Rouse's account of the narrative dimension of scientific practice:

> i) first, the epistemic importance of narrative should not be confined to a specific group of disciplines, domains of inquiry, or objects of knowledge. Narrative understanding is characteristic of any scientific practice;
>
> ii) second, more important than the form in which the results of investigation are written, is the ways in which the practices of scientific research and the resultant knowledge acquire their intelligibility and significance from being situated within narratives;
>
> iii) third, the intelligibility of action and of the things we encounter or use in acting depends on their already belonging to a field of possible narratives;
>
> iv) and lastly, the epistemic significance of narrative should not be seen in terms of completed narratives. In the narrative fields of scientific practice there is no unitary authorial point of view, but multiple authors that engage in an ongoing struggle to determine the configuration of the narrative within which they are all situated. Because current scientific research does not simply focus on what will happen next, but continually reconfigures its own past, scientific understanding must be situated within narratives in continual re-construction.

According to Rouse these four considerations can be summarized in a single claim: "the intelligibility, significance, and justification of science knowledges stem from their already belonging to continually reconstructed narrative contexts supplied by the ongoing practices of scientific research" (Rouse, 1996: 161).

2.3.1 Narrative analysis

> "*If narratives are tools and if the crafting and sharing of stories involve morals, then a discussion of ethics is a necessary component of narrative inquiry*" (Adams, 2008: 177).

Rouse's account of the narrative dimension of scientific practice offers a privileged perspective from which to address my research questions. Indeed, one possible way of looking at the geoengineering issue and the scalar dislocations it introduces into modern systems of experience and understanding is to explore the social and ethical implications of geoengineering by adopting expanded notions of narrative, which account for particular ways of rendering the world in both visual and verbal forms.

By contending that reasoning can be discovered in all sorts of symbolic actions (non-discursive as well as discursive) Walter Fisher introduced the concept of narrative rationality, suggesting that its application to specific stories[11] may further clarify its nature and value (Fisher, 1987; Fisher, 1985).

> "The perspective of narrative rationality does not exclude the long tradition of rhetorical logic; it is a rhetorical logic itself. Other rhetorical logics, however, have dwelt on argument, argumentative genres, and specific standards of argumentative assessment. The perspective of narrative rationality focuses on all forms of human communication as carriers of good reasons and on a system of evaluation that incorporates the available standards of argumentative assessment but offers additional considerations (...) the concept of narrative rationality offers systematic principles, procedures, and criteria for assessing elements of discourse that provide warrants for believing or acting in particular ways" (Fisher, 1987: 49).

It is in line with these ideas that I propose to analyse the narratives of geoengineering. Within the framework of Fisher's "narrative paradigm", I argue that both the descriptive and explanatory elements of geoengineering narratives need to be examined in order to better understand the role specific structures play in satisfying the demands of

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[11] Although recognizing that technical communities have their own conceptions and criteria for judging the rationality of communication, Fisher considered that *'the work even of scientists is inspired by stories, hence their discourse can be interpreted usefully from the narrative perspective'* Fisher WR. (1984) Narration as human communication paradigm: The case of public moral argument. *Communication Monographs* 51: 1-22.

probability and fidelity of geoengineering proposals. The descriptive and explanatory elements of a narrative point toward the two different kinds of narrative research described by Polkinghorne: the descriptive narrative research aims “to render the narrative accounts already in place which are used by individuals or groups as their means for ordering and making temporal events meaningful"; the explanatory narrative research seeks "to construct a narrative account explaining 'why' a situation or event involving human actions has happened” (Polkinghorne, 1988: 161). I expect that the first kind of narrative research may help to disentangle the various (conflicting?) narrative schemes that lie underneath the representations of geoengineering – narrative schemes that operate not only in the realm of rationality, knowledge, and facts, but also in the realm of subjectivity, values, imagination, and fiction. However, it is only within an explanatory narrative approach that I will be able to address the fundamental question of why geoengineering is gaining more serious consideration and becoming an increasingly plausible solution to tackle climate change. Because explanatory narrative research is retrospective and retrodictive, adopting this kind of approach does not seem an easy task when considering the ongoing debates on geoengineering. Nonetheless, because an analogy can be made with prior, already-told stories – of which "the pathological history of weather and climate modification" is just one example (Fleming, 2010) –, I believe this task is not only possible, but also an imperative:

> ″I can only answer the question “What am I to do?” if I can answer the prior question “Of what story or stories do I find myself a part?” We enter human society, that is, with one or more imputed characters — roles into which we have been drafted — and we have to learn what they are in order to be able to understand how others respond to us and how our responses to them are apt to be construed″ (MacIntyre, 1984: 216).

It is important, however, to recognise the resistance put up by science to this kind of investigation. In fact, explanatory narrative research is not typically used in the sciences, partly because “narrative truth is distinguished from other kinds of formal science truths by its emphasis on the life-like, intelligible and plausible story. Stories typically reflect a coherence (as opposed to correspondence) theory of truth in that the narrator strives for narrative probability — a story that makes sense; narrative fidelity — a story consistent with past experiences or other stories; and aesthetic finality — a story with satisfactory closure and representation appeal" (Sandelowski, 1991: 164-165).

In the context of this discussion, which points to some of the presuppositions that underpin Fisher's narrative paradigm (Fisher, 1987: 64-65; Fisher, 1984), it is important to emphasise the difference between the elements of narrative theory, a theoretical distinction stressed by structuralists who considered that each narrative has two parts: a story (what is depicted in a narrative - the content) and the discourse (how it is depicted - the expression). According to Chatman (1978: 19-22), the story consists of the content or chain of events (actions and happenings) and the existents (characters and items of setting), while the discourse refers to the means by which the content is communicated, thus comprising two subcomponents: the narrative form itself (the structure of narrative transmission) and its manifestation (its appearance in a specific materializing medium). In order to capture all elements of the communicative situation, Chatman reminds us that narrative is a semiotic structure, which presupposes a form and a substance of expression and a form and a substance of content (Figure 1).

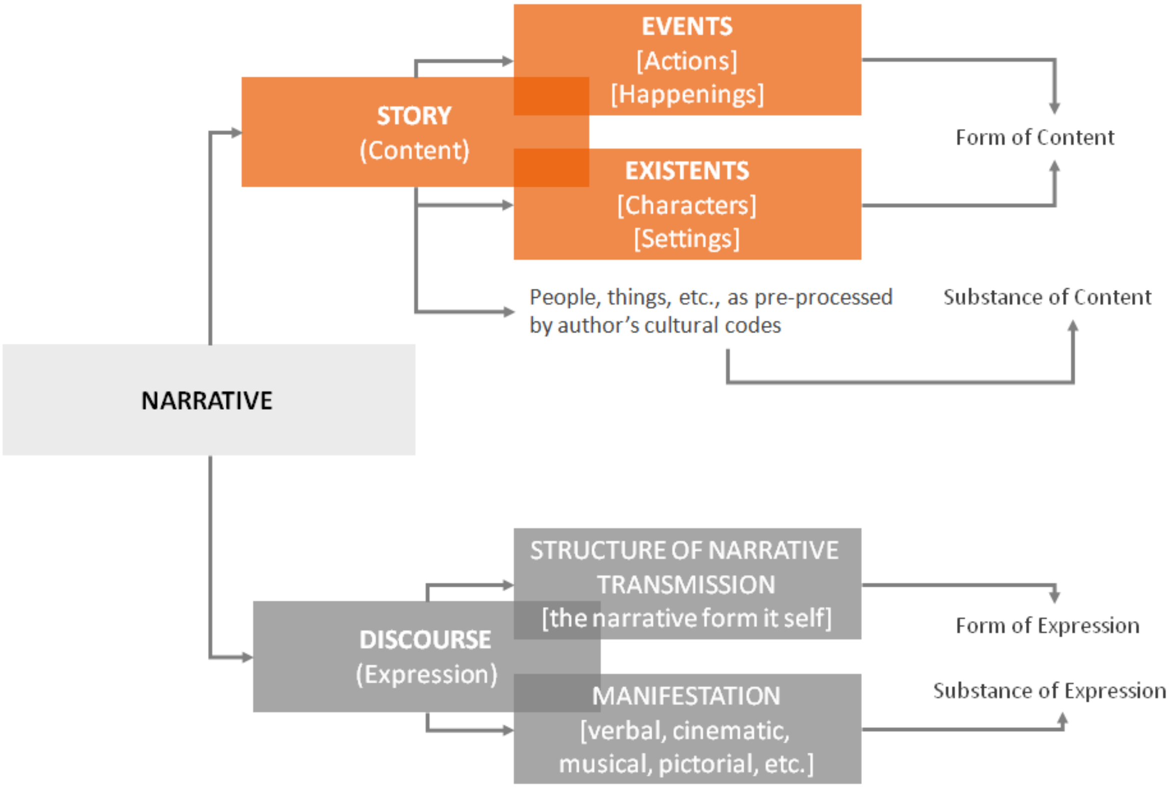

Figure 1 - Elements of narrative theory (Adapted from Chatman, 1978, p. 29).

2.3.2 Visual Narrative Analysis

> "*(...) if images, as we claim, do not merely illustrate theoretical views, but are means of arriving at and embodying such views, then a history of science limited to theoretical and textual pronouncements misses part of the action*" (Cambrosio et al., 2005: 190).

The universe of geoengineering is filled with all sorts of imageries. These imageries seem to fill the "visual science continuum" that has at one extreme the set of figures that convey data and, at the other, scientific illustrations, i.e. “representations of how something might or could be” (Ottino, 2003: 474). They are all part of the geoengineering story, revealing facts, knowledge, values, fears, desires, promises, anxieties, incredulity, about not only the idea of deliberately manipulating Earth’s climate to offset anthropogenic climate change, but also, and above all, what we know about the world and how we make sense of our place in it.

Against this background, I suggest the relevance of examining the visual representations of geoengineering in order to understand how they use a narrative way of structuring thought to make sense of a *geoengineered world.* Therefore, I also adopt a visual narrative approach to interpret and assess the sense-making structures of a set of pictorial narratives of geoengineering, as well as to identify the particular instance of these narratives that provide (or not) a reliable, trustworthy, and desirable guide to thought and action.

The rationale behind this approach is twofold. First, by acknowledging that the visual modes of representation (that are integral to many kinds of thinking) function as a powerful method of meaning making, and that pictorial expressions are not qualitatively different from verbal expressions (Barbatsis, 2005), it seems opportune to draw attention to the concepts of “narrative rationality” (Fisher, 1987; Fisher, 1985) and “imag[in]ing” (Ruivenkamp and Rip, 2011) in order to explore the way geoengineering images convey plausible, or implausible, arguments about current proposals to intentionally modify the global climate and how a geoengineered world could be. The second assumption underlying this approach is that the pictorial representations of geoengineering can also provide valuable insights into its objects of research, an issue that has not received a great deal of attention but seems particularly relevant when considering the social and ethical implications of geoengineering proposals.

Accordingly, and based on the conceptual framework proposed by Pauwels for the analysis of visual representations in science (Pauwels, 2006), I will attempt to understand how particular images of geoengineering work to persuade, and how they produce their effects of "truth". By taking into consideration the “diversity that exists with regard to types of translation processes and actors in the production cycle, as well as the different purposes and intents of representations and specific contexts of use” (Idem: 4), Pauwels' framework provides a rationale to address the complex process of meaning-making that has an “impact on what can be known and how, on what is revealed or obscured, and on what is included or excluded” (Idem: 5). In order to highlight processes of persuasion that may otherwise be difficult to detect I will focus my analysis on the broad amplitude of intended or unintended choices that may influence visual representation. This broad amplitude of the representational space, in what Pauwels refers to as the “visual representational latitude”, is determined by the nature of the problem being depicted (type of referent), by the intentional and unintentional choices of the author (the context of production), and also by the characteristics of the audience in relation to a particular visual representation (the context of use).

3. BACKGROUND

What is climate geoengineering? Why has it recently emerged as a topic of interest and discussion within the climate science community? Why is there a need to consider the social and ethical implications of geoengineering proposals? In this section I will address these three questions in order to present the background and relevance of this research.

3.1. Why Geoengineering?

The carbon dioxide theory of climate change and the global warming forecast are not new issues. This is aptly captured in the book *Historical Perspectives on Climate Change*, in which James Fleming examines the historical roots of global climate change as a field of inquiry, from the Enlightenment to the late twentieth century, to provide an insightful, reflexive account of the paths through which we have arrived at our current state of knowledge and "apprehension"[12] of climate change (1998). By looking back to the work of scientists such as Joseph Fourier, John Tyndall, Svante Arrhenius, T. C. Chamberlin, Ellsworth Huntington, G. S. Callendar, Gilbert Plass, Hans Suess, and Roger Revelle he explores the historical relationships among the numerous and quite varied theories about climatic change and concludes that "the modern, scientific description of weather and climate has been gradually established since about the mid-nineteenth century" (Idem: 136).

Although our understanding of the complex processes that affect both the Earth's energy balance and the energy flows within the global climate system has increased progressively and significantly over the past two centuries, and we know a good deal more than ever before about the anthropogenic greenhouse effect and its influence on

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[12] Fleming uses the term "apprehension" in its threefold sense: (1) awareness or understanding, (2) anticipation or dread, and (3) intervention (Idem: 5).

global climate change, the very latest scientific evidence on climate change provides little cause for optimism.

According to the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC, 2013b) the concentrations of the atmospheric greenhouse gases (GHGs) carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) have increased by about 40%, 150%, and 20%, respectively, since the beginning of the Industrial Era[13] as a result of anthropogenic emissions from fossil fuel combustion, agriculture, and land-use changes (Figure 2).

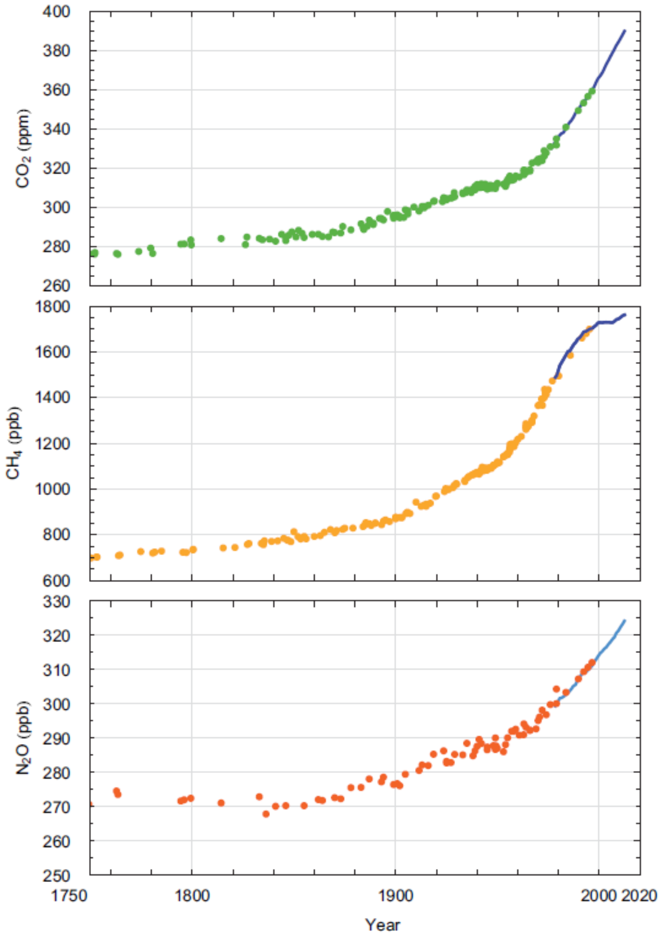

Figure 2 - Atmospheric CO_2, CH_4, and N_2O concentrations history over the industrial era determined from air enclosed in ice cores and firn air (colour symbols) and from direct atmospheric measurements (blue lines, measurements from the Cape Grim observatory) (MacFarling Meure et al., 2006) (Source: Ciais et al., 2013).

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[13] The tropospheric mixing ratio of CO_2 has increased globally from 278 ppm in 1750 to 390.5 ppm in 2011. During the same time interval, CH_4 increased from 722 ppb to 1803 ppb, and N_2O from 271 ppb to 324.2 ppb.

The current atmospheric concentration of these GHG substantially exceed the highest concentrations recorded in ice cores during the past 800,000 years and their mean rates of increase over the past century are unprecedented with respect to the ‘highest resolution’ ice core records of the last 22,000 years (IPCC, 2013c).

This increase is the main driving cause of climate change. By reducing the flux of outgoing long-wave radiation from the Earth to space (trapping of long-wave radiation), the increasing atmospheric concentration of these (CO_2, CH_4, and N_2O) and other GHGs (e.g. halocarbons, O_3) has been changing the balance between the incoming solar radiation and the outgoing infrared radiation emitted by the Earth. As recently observed changes in the climate system indicate, these perturbations in the radiative energy budget of the Earth's climate system - often described in terms of Radiative Forcing (RF)[14] - can have a profound influence on the Earth's climate and, consequently, on the Earth system as a whole.

As seen in Figure 3, the total anthropogenic RF for 2011 (3.33 W m^{-2}) relative to 1750 (1.13 W m^{-2}) is 2.29 W m^{-2}.[15] Altogether the above-mentioned three GHGs (CO_2, CH_4, and N_2O) amount to 80% of the total radiative forcing (RF) from well-mixed greenhouse gases (WMGHGs)[16]. Emissions of CO_2 have made the largest contribution to the

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[14] The concept of radiative forcing provides a way to quantify the net change in the energy balance of the Earth system at the top of the atmosphere as a result of an externally imposed change. It is usually expressed in watts per square meter (W $m^{-2)}$ averaged over a particular period of time. For a wide range of forcings there is a nearly linear relationship between the RF and the resulting equilibrium response of global mean surface temperatures (GMST) as simulated in general circulation models (National Research Council 2005), making it valuable for comparing the influence on GMST of most individual agents affecting the Earth’s radiation balance.

[15] This estimate is 43% higher than that reported in AR4 for the year 2005. This difference is primarily due to the continued growth in most GHGs concentrations (positive RF), but also to improved estimates of RF by aerosols, which indicate a weaker net cooling effect (negative RF) Myhre G, D. Shindell, F.-M. Bréon, W. Collins, J. Fuglestvedt, J. Huang, D. Koch, J.-F. Lamarque, D. Lee, B. Mendoza, T. Nakajima, A. Robock, G. Stephens, T. Takemura and H. Zhang. (2013) Anthropogenic and Natural Radiative Forcing. In: Stocker TF, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (ed) *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press, 659-740.

[16] Well-mixed greenhouse gases (WMGHGs) are those GHGs "that are sufficiently mixed throughout the troposphere that concentration measurements from a few remote surface sites can characterize the climate-relevant atmospheric burden; although these gases may still have local variation near sources and sinks and even small hemispheric gradients. Global forcing per unit emission and emission metrics for

increased anthropogenic RF, accounting for about 56% (1.68 W m^{-2}) of the total RF of WMGHGs from 1750 to present time.

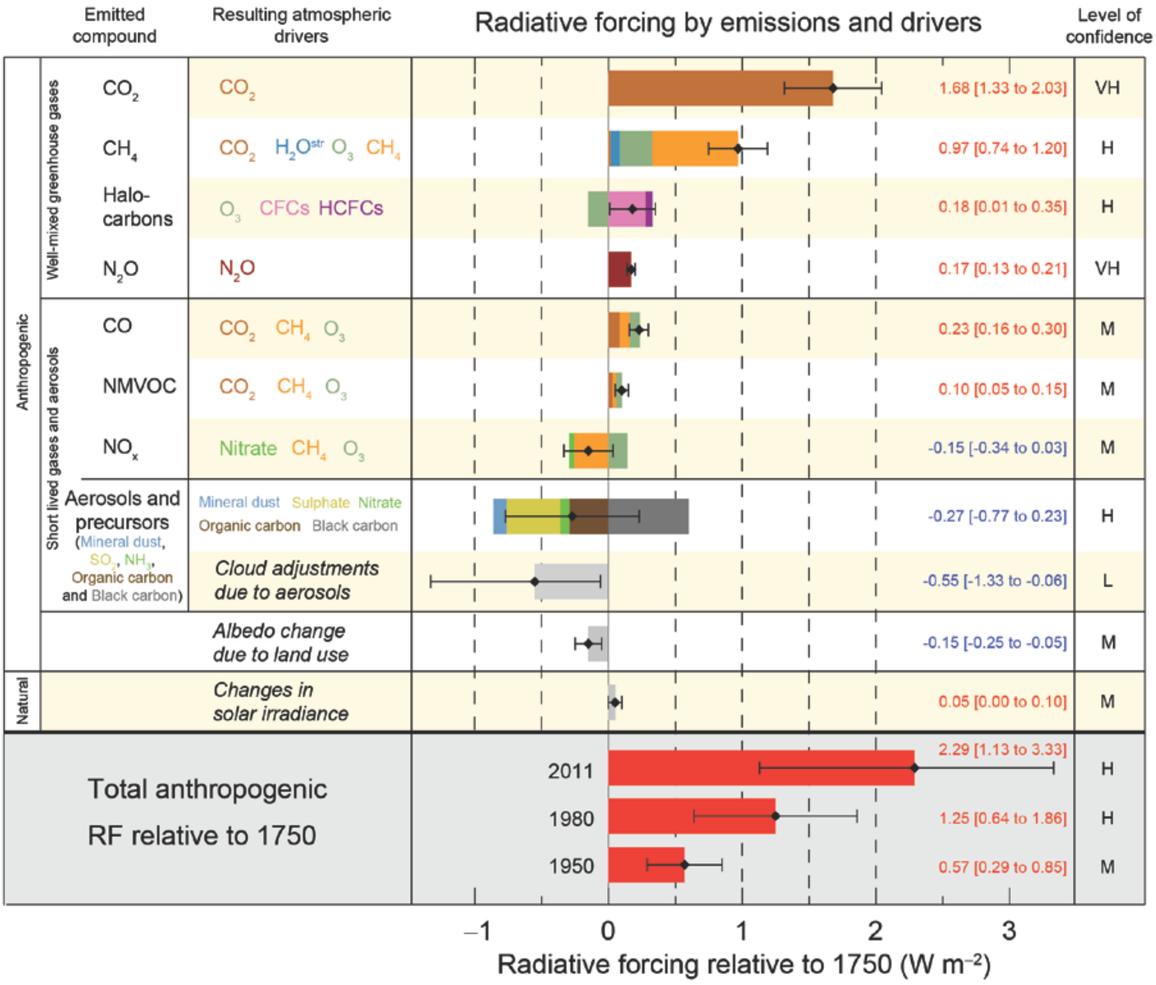

Figure 3 - Radiative forcing estimates in 2011 relative to 1750 and aggregated uncertainties for the main drivers of climate change. Values are global average radiative forcing (RF), partitioned according to the emitted compounds or processes that result in a combination of drivers. The best estimates of the net radiative forcing are shown as black diamonds with corresponding uncertainty intervals; the numerical values are provided on the right of the figure, together with the confidence level in the net forcing (VH – very high, H – high, M – medium, L – low, VL – very low). Albedo forcing due to black carbon on snow and ice is included in the black carbon aerosol bar. Small forcings due to contrails (0.05 W m^{-2}, including contrail induced cirrus), and HFCs, PFCs and SF_6 (total 0.03 W m^{-2}) are not shown. Concentration-based RFs for gases can be obtained by summing the like-coloured bars. Volcanic forcing is not included as its episodic nature makes is difficult to compare to other forcing mechanisms. Total anthropogenic radiative forcing is provided for three different years relative to 1750 (IPCC, 2013c: 14).

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these gases thus do not depend on the geographic location of the emission, and forcing calculations can assume even horizontal distributions. These gases, or a subset of them, have sometimes been referred to as 'long-lived greenhouse gases' as they are well mixed because their atmospheric lifetimes are much greater than the time scale of a few years for atmospheric mixing, but the physical property that causes the aforementioned common characteristics is more directly associated with their mixing within the atmosphere. WMGHGs include CO_2, N_2O, CH_4, SF_6, and many halogenated species" Ibid.

Recent observations have also strengthened the evidence that anthropogenic increases in the WMGHGs have substantially enhanced the greenhouse effect and the resulting forcing continues to increase. As seen in Figure 4(b) the forcing from CO_2 and other WMGHGs has increased significantly faster since the 1960s and evidence has grown since the Fourth Assessment Report (AR4) of the IPCC that the widespread changes observed in the climate system in the latter half of the last century (Figure 5) are primarily due to the anthropogenic increase in greenhouse gas concentrations and other anthropogenic forcings together. These results strengthen the conclusion that human activity is the dominant cause of observed warming since the mid-20th century.

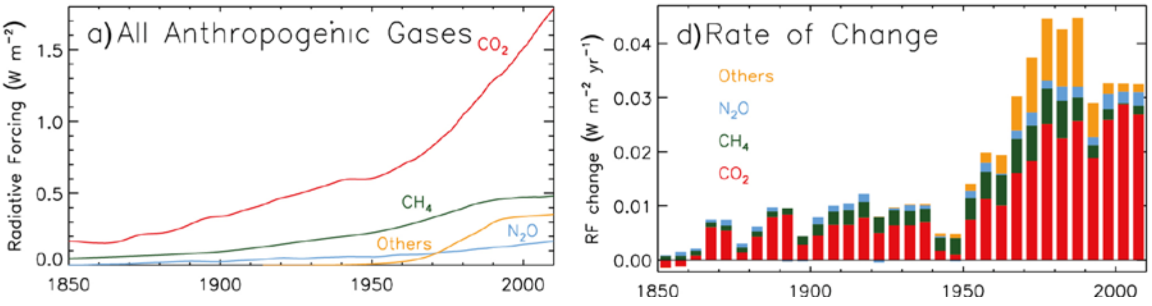
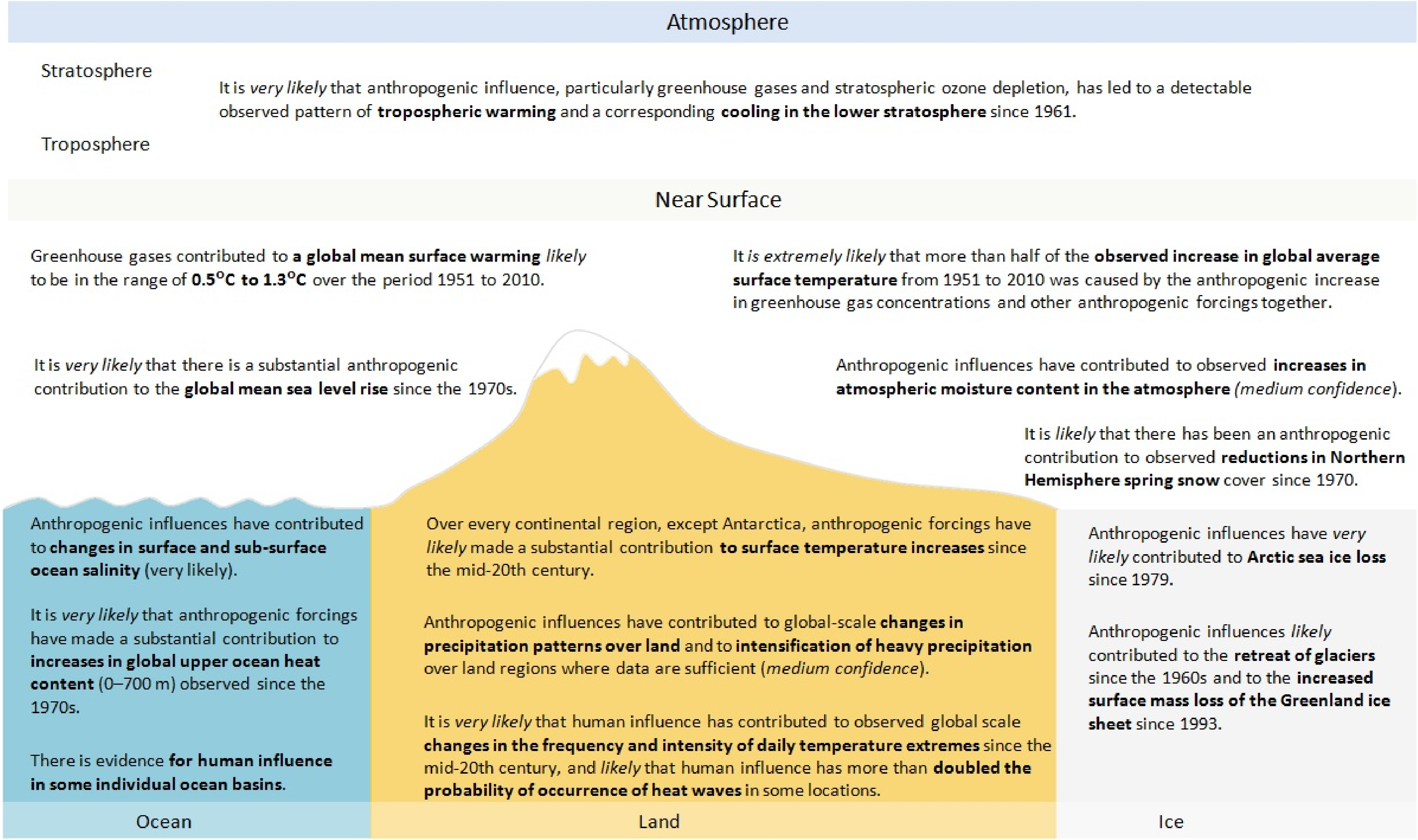


Figure 4 - (a) Radiative forcing (RF) from the major WMGHGs and groups of halocarbons from 1850 to 2011. (b) Rate of change in forcing from the major WMGHGs and groups of halocarbons from 1850 to 2011 (Source: Myhre, 2013: 677).

During 2002–2011, atmospheric CO_2 concentrations increased at a rate of 1.9 to 2.1 ppm yr^{-1}. This decadal rate of increase is higher than those observed during any previous decade since direct atmospheric concentration measurements began in 1958 (Ciais et al., 2013: 467).

Current concentration of GHGs have already contributed to an increase of the Global Mean Surface Temperature (GMST) of 0.85°C [0.65 to 1.06]°C over the period 1880-2012. Despite the cooling effect of the Mt. Pinatubo volcanic eruption in 1991, the past three decades have been among the warmest since 1860. The observed increase in GMST from 1951 to 2010 is approximately 0.6°C to 0.7°C and it is extremely



It is *very likely* that anthropogenic influence, particularly greenhouse gases and stratospheric ozone depletion, has led to a detectable observed pattern of **tropospheric warming** and a corresponding **cooling in the lower stratosphere** since 1961.

Greenhouse gases contributed to **a global mean surface warming** *likely* to be in the range of **0.5°C to 1.3°C** over the period 1951 to 2010.

It *is extremely likely* that more than half of the **observed increase in global average surface temperature** from 1951 to 2010 was caused by the anthropogenic increase in greenhouse gas concentrations and other anthropogenic forcings together.

It is *very likely* that there is a substantial anthropogenic contribution to the **global mean sea level rise** since the 1970s.

Anthropogenic influences have contributed to observed **increases in atmospheric moisture content in the atmosphere** (*medium confidence*).

It is *likely* that there has been an anthropogenic contribution to observed **reductions in Northern Hemisphere spring snow** cover since 1970.

Anthropogenic influences have contributed to **changes in surface and sub-surface ocean salinity** (very likely).

It is *very likely* that anthropogenic forcings have made a substantial contribution to **increases in global upper ocean heat content** (0–700 m) observed since the 1970s.

There is evidence **for human influence in some individual ocean basins.**

Over every continental region, except Antarctica, anthropogenic forcings have *likely* made a substantial contribution **to surface temperature increases** since the mid-20th century.

Anthropogenic influences have contributed to global-scale **changes in precipitation patterns over land** and to **intensification of heavy precipitation** over land regions where data are sufficient (*medium confidence*).

It is *very likely* that human influence has contributed to observed global scale **changes in the frequency and intensity of daily temperature extremes** since the mid-20th century, and *likely* that human influence has more than **doubled the probability of occurrence of heat waves** in some locations.

Anthropogenic influences have *very likely* contributed to **Arctic sea ice loss** since 1979.

Anthropogenic influences *likely* contributed to the **retreat of glaciers** since the 1960s and to the **increased surface mass loss of the Greenland ice sheet** since 1993.

Figure 5- Overview of some of the main observed climate change indicators as listed in AR5 (cf. footnote 17 for a description of the terms in italic, as used in the IPCC's AR5 to indicate the assessed likelihood of an outcome or a result. See Chapter 10 and Table 10.1 for further details).

likely[17] that the observed increase in anthropogenic greenhouse gas concentrations has been the dominant cause of the observed warming since the mid-20th century[18].

Furthermore, it is now clear that some degree of climate change is already inevitable as the impacts over the next decades have been determined by past and present emissions. Indeed, even if we do not take into account the problem of political and socio-economic inertia that led us to the current situation, and consider the implausible "zero emissions" scenario where we were to halt all human-induced emissions today (also termed "geophysical warming commitment"), the warming commitment[19] by the end of this century would still be an additional 0.7°C above pre-industrial levels (Hare and Meinshausen, 2006). This inevitable delay between cutting emission of GHGs and the point at which anthropogenic climate change will cease is mainly due to the large ocean inertia, slow processes in the cryosphere and land surfaces, and the long lifetime of many greenhouse gases (primarily CO_2).

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[17] All three IPCC Working Groups in the AR5 have agreed to use two metrics for communicating the degree of certainty in key findings: (i) Confidence in the validity of a finding based on the type, amount, quality, and consistency of evidence (e.g., data, mechanistic understanding, theory, models, expert judgment) and the degree of agreement. Confidence is expressed qualitatively (from very low to very high). (ii) Quantified measures of uncertainty in a finding expressed probabilistically (based on statistical analysis of observations or model results, or expert judgement): Virtually certain 99–100% probability, Very likely 90–100%, Likely 66–100%, About as likely as not 33–66%, Unlikely 0–33%, Very unlikely 0–10%, Exceptionally unlikely 0–1%. The following additional terms were also used to indicate the assessed likelihood of an outcome or a result: Extremely likely: 95–100%, More likely than not >50–100%, and Extremely unlikely 0–5%Mastrandrea MD, Mach KJ, Plattner G-K, et al. (2011) The IPCC AR5 guidance note on consistent treatment of uncertainties: a common approach across the working groups. *Climatic Change* 108: 675-691, Mastrandrea MD, Field CB, Stocker TF, et al. (2010) *Guidance Note for Lead Authors of the IPCC Fifth Assessment Report on Consistent Treatment of Uncertainties*: Intergovernmental Panel on Climate Change (IPCC).

[18] GHGs contributed to a global mean surface warming likely to be in the range of 0.5°C to 1.3°C over the period 1951 to 2010 IPCC. (2013c) Summary for Policymakers. In: Stocker TF, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (ed) *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press, 1-29.

[19] The concept of warming commitment has been used to convey the magnitude and time scales of inertia in the climate system with respect to human induced increases in greenhouse gas concentrations. The concept of ‘geophysical warming commitment’ defines the warming commitments from a purely geophysical perspective, as the warming that would result from a complete and abrupt cessation of all human-induced emissions Hare B and Meinshausen M. (2006) How Much Warming are We Committed to and How Much can be Avoided? *Climatic Change* 75: 111-149.The value of this concept relies on the fact that it shows the timescales of the climate system without implicit entanglements with socio-economic assumptions.

Cumulative emissions of CO_2 are therefore expected to be the dominant driver of future climate change. In fact, CO_2 represents about 80 to 90% of the total anthropogenic forcing in all Representative Concentration Pathways (RCPs)[20] scenarios over the 21st century (Collins, 2013: 1031). As can be seen in Figure 6, a consistent and robust feature across all RCP scenarios is the similar warming rate until the middle of this century – clearly demonstrating the warming commitment from current atmospheric composition and from past emissions. At longer time scales, the warming rate begins to depend more on the specified GHG concentration pathway associated with each RCP scenario, being highest (>0.3°C per decade) in the RCP8.5 scenarios and significantly lower in the RCP2.6, which assumes strong mitigation actions, as well as the use of large-scale bio-energy with carbon capture and storage (BECCS)[21] to achieve globally negative emissions after around 2080.

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[20] Four Representative Concentration Pathway (RCP) scenarios produced from Integrated Assessment Models (IAMs) were used in the Fifth Assessment Report of IPCC as a basis for the climate predictions and projections presented by WGI (AR5 WGI report, chapters 11 to 14). These four RCPs are identified by their approximate total radiative forcing in year 2100 relative to 1750: 2.6 $W\ m^{-2}$ for RCP2.6, 4.5 $W\ m^{-2}$ for RCP4.5, 6.0 $W\ m^{-2}$ for RCP6.0, and 8.5 $W\ m^{-2}$ for RCP8.5.

[21] BECCS is a form of geoengineering, as described in the following section.

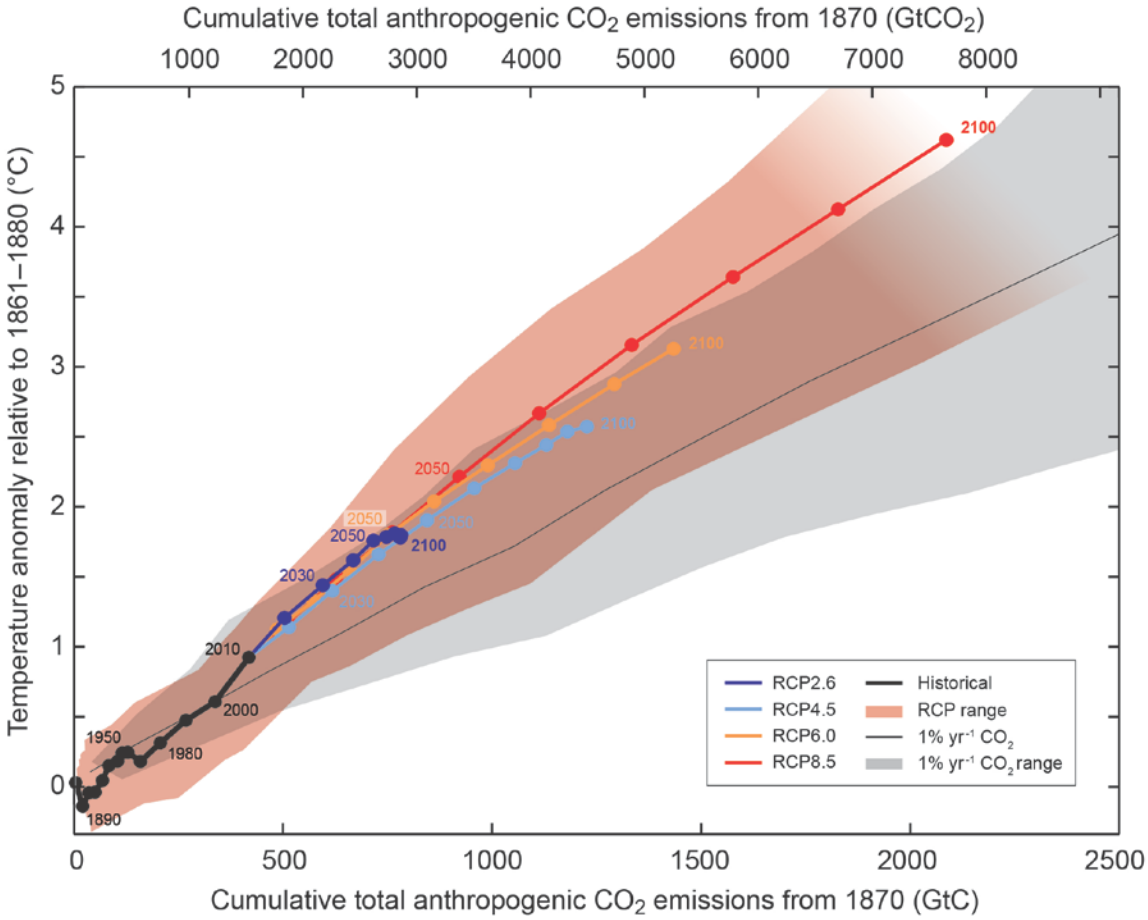

Figure 6 - Global mean surface temperature increase as a function of cumulative total global CO_2 emissions from various lines of evidence. Multimodel results from a hierarchy of climate-carbon cycle models for each RCP until 2100 are shown with coloured lines and decadal means (dots). Some decadal means are labeled for clarity (e.g., 2050 indicating the decade 2040–2049). Model results over the historical period (1860 to 2010) are indicated in black. The coloured plume illustrates the multi-model spread over the four RCP scenarios and fades with the decreasing number of available models in RCP8.5. The multi-model mean and range simulated by CMIP5 models, forced by a CO_2 increase of 1% per year (1% yr^{-1} CO_2 simulations), is given by the thin black line and grey area. For a specific amount of cumulative CO_2 emissions, the 1% per year CO_2 simulations exhibit lower warming than those driven by RCPs, which include additional non-CO_2 forcings. Temperature values are given relative to the 1861–1880 base period, emissions relative to 1870. Decadal averages are connected by straight lines (Source: IPCC, 2013c: 28).

With these latest findings of the IPCC's AR5 report in the foreground it seems clear that the advances in the scientific understanding of global climate change since the mid-nineteenth century was concomitant with an unprecedented change in our environment. Indeed, our scientific understanding of the complex processes that affect both the Earth's energy balance and the energy flows within the global climate system has been continuously challenged by the increasing human interference with Earth's climate [22]. This is made clear by M. Jarraud and A. Steiner in the Foreword to the Working Group I contribution to the IPCC's Fifth Assessment Report:

> "The report confirms that warming in the climate system is unequivocal, with many of the observed changes unprecedented over decades to millennia: warming of the atmosphere and the ocean, diminishing snow and ice, rising sea levels and increasing concentrations of greenhouse gases. Each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850. These and other findings confirm and enhance our scientific understanding of the climate system and the role of greenhouse gas emissions" (IPCC, 2013b: v).

The recognition that key environmental parameters have moved well beyond the range of natural variability and the prospect that human influences on the climate system may trigger abrupt climate change have contributed to a growing sense of urgency and have given further impetus to the idea that transformational actions to address climate change need to be scaled up. As a result, attention is increasingly focused on what can be done to manipulate the climate with the primary intention of reducing undesired climate change caused by human influences. This idea lies at the core of what has been termed "geoengineering" (or "climate engineering").

3.2 What is Geoengineering?

Geoengineering is a term that refers to "a broad set of methods and technologies that aim to deliberately alter the climate system in order to alleviate the impacts of climate change" (IPCC, 2012: 2). Although proposed geoengineering methods vary greatly in terms of their technological characteristics, modes of action, and potential side effects, they are usually subdivided into two broad categories: Carbon Dioxide Removal (CDR) and Solar Radiation Management (SRM) methods (The Royal Society, 2009; IPCC, 2012) . Figures 7 and 8 depict the most commonly discussed geoengineering methods in both these categories.

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[22] For a detailed description of the observed impacts and indicators of a changing climate, see: Field CB, Barros VR, Dokken DJ, et al. (2014) Technical Summary. *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Carbon Dioxide Removal

CDR covers a wide range of methods that seek to remove CO_2 from the atmosphere, and which are intended to cool the planet by reducing the absorption of long-wave (thermal infrared) radiation in the atmosphere. As can be seen in Figure 7, many of these methods are designed to enhance natural physical, biological, or chemical processes that capture and store CO_2 in the ocean and land.

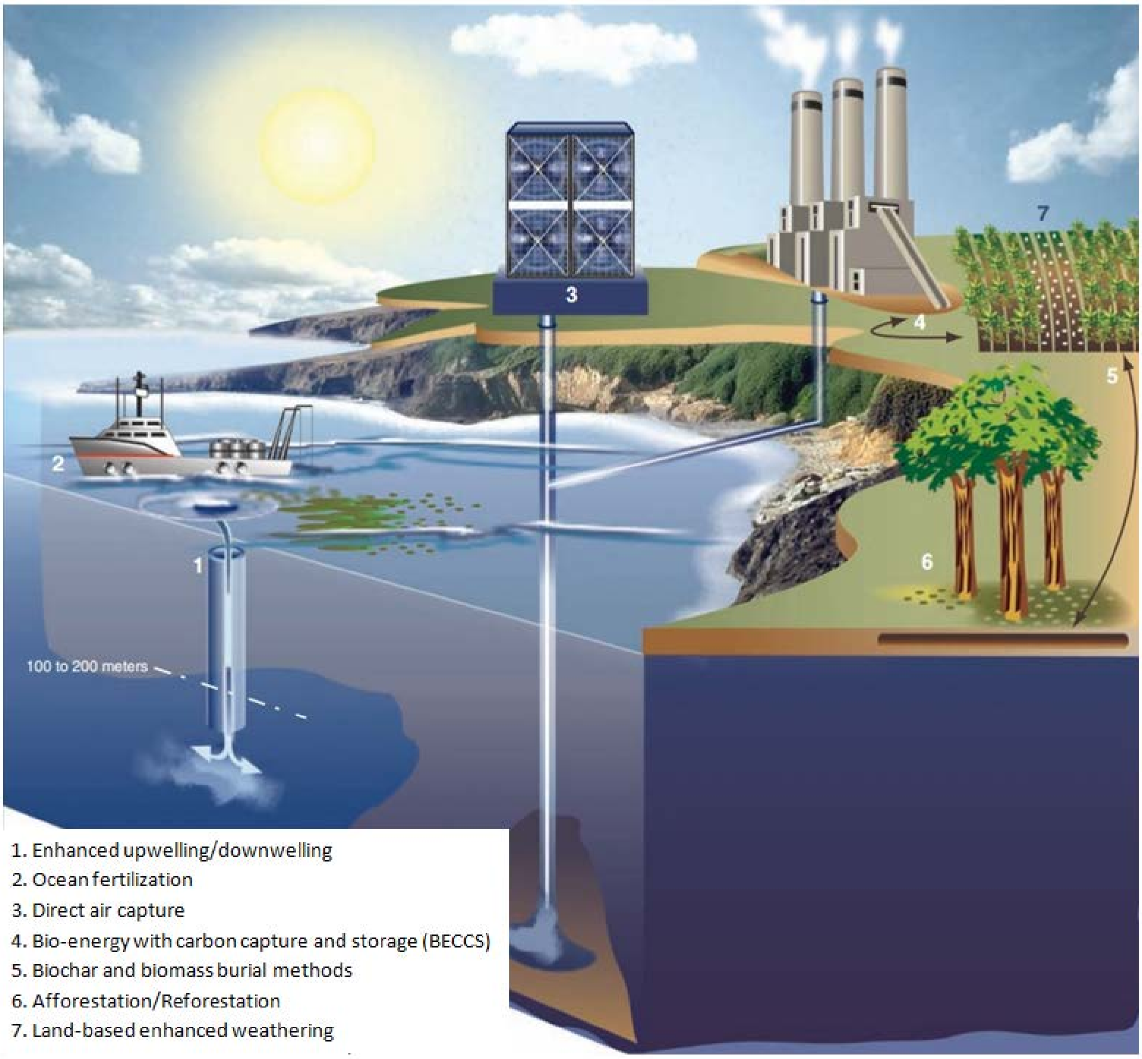

Figure 7 - Illustration of the most widely discussed Carbon Dioxide Removal methods (Source: GAO, 2010: 11).

Despite the major uncertainties surrounding the global potential of all CDR methods (Haszeldine and Scott, 2014; The Royal Society, 2009), a recent study estimates that the global physical potential[23] of different CDR methods at present is 1.5-3 PgC yr^{-1}, of which 0.55-0.76 PgC yr^{-1} has already been realised through afforestation and inadvertent ocean fertilisation (Lenton, 2014). According to this same study, the total CDR potential (without considering direct air capture) is estimated to reach 4-9 PgC yr^{-1} by the middle of this century, and 9-26 PgC yr^{-1} by the end of the century. However, as we will see next, CDR methods raise complex issues related primarily to scale, cost, effectiveness and local environmental consequences (Caldeira et al., 2013).

What follows is a brief description of the most widely discussed CDR methods as they have been presented to date.

- **1. Enhanced upwelling/downwelling** - One of the ocean-based approaches to reduce the levels of CO_2 in the atmosphere is based on the idea that the rate of atmospheric carbon sequestration may be enhanced through the manipulation of the overturning circulation of the oceans (The Royal Society, 2009; Vaughan and Lenton, 2011; Yool et al., 2009). This could be accomplished by either enhancing upwelling rates locally, using vertical pipes to bring nutrient-rich deep waters to surface waters to promote phytoplankton growth (Lovelock and Rapley, 2007; Karl and Letelier, 2008), or by enhancing downwelling of CO_2-rich waters from the surface layers of the oceans to lower depths (Zhou and Flynn, 2005). A recent study of the first of these proposals reveals that, "under the hypothetical and most optimistic assumptions of a massive deployment of perfect ocean pipes", climate engineering by artificial ocean upwelling would lead to a atmospheric CO_2 sequestration rate of about 0.9 PgC yr^{-1} (Oschlies et al., 2010) [24]. According to the simulation results of the model used in this study[25],

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[23] The physical potential of CDR does not take into consideration the social, economic, and engineering constraints.

[24] This value corresponds approximately to one "stabilization wedge", as proposed by Pacala and Solow Pacala S and Socolow R. (2004) Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies. *Science* 305: 968-972.

[25] The University of Victoria (UVic) Earth System Climate Model Weaver AJ, M. Eby, E. C. Wiebe, et al. (2001) The UVic Earth System Climate Model: Model description, climatology, and applications to past, present and future climates. *Atmospheric Sciences* 39: 361-428., in the configuration described by

a sudden termination of artificial upwelling would lead to a concomitant rise in atmospheric concentration of CO_2 and surface temperature. Because artificial upwelling is expected to increase the imbalance of the radiative energy budget of the Earth's climate system, the rise in atmospheric concentration of CO_2 and surface temperature would be even greater than those experienced now[26]. In addition, most of the CO_2 sequestered by artificial ocean upwelling would be stored on land and not in the ocean, which would make the monitoring and evaluation processes of this CDR method extremely difficult. Assessments of the second above described method also suggest that it is highly unlikely that modifying downwelling ocean currents may be considered a competitive method of carbon sequestration due to the combination of high costs and uncertainty of effectiveness (Zhou and Flynn, 2005; Vaughan and Lenton, 2011).

- **2. Ocean fertilisation** - Ocean fertilisation methods involved adding 'limiting nutrients' (especially iron, but also silicates, phosphorus, nitrogen, calcium hydroxide, and/or limestone) to the surface ocean to stimulate biological productivity and thus increase the uptake of CO_2 from the atmosphere. The quantity of nutrients needed to have an effect on the carbon cycle is largely dependent on the relative amounts of elements which algae use in building their organic tissue (Sarmiento and Gruber, 2002; The Royal Society, 2009). The most widely studied method of artificial ocean fertilisation consists in the addition of iron to ocean regions that are nutrient rich but have low stocks of phytoplankton

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Schmittner *et al* Schmittner A, Oschlies A, Matthews HD, et al. (2008) Future changes in climate, ocean circulation, ecosystems, and biogeochemical cycling simulated for a business-as-usual CO2 emission scenario until year 4000 AD. *Global Biogeochemical Cycles* 22: GB1013.

[26] This is what has been called the "termination effect", i.e. the climatic consequences of a sudden halt or failure of a geoengineering systemUK House of Commons. Science and Technology Committee. (2010) The Regulation of Geoengineering. *Fifth Report of Session 2009–10.* London: The Stationery Office Limited: House of Commons. Science and Technology Committee, 116. Although it has been mainly used to describe the potential climatic impacts resulting from an abrupt termination of the use of SRM methods in the future Jones A, Haywood JM, Alterskjær K, et al. (2013) The impact of abrupt suspension of solar radiation management (termination effect) in experiment G2 of the Geoengineering Model Intercomparison Project (GeoMIP). *Journal of Geophysical Research: Atmospheres* 118: 9743-9752, Schultz C. (2013) Sudden geoengineering termination could cause a huge warming spike. *EOS, Transactions American Geophysical Union* 94: 512-512., the "termination effect" is also a valid concept when considering CDR methods.

due to a lack of iron (the so-called High Nitrate Low Chlorophyll regions - HNLC). Adding massive amounts of iron to these low iron HNLC regions would stimulate the biological pump[27] and potentially increase the transfer of carbon from the surface water into the deep sea-floor[28].

Ocean Iron fertilisation (OIF) differs from other geoengineering methods in two fundamental aspects. The first of these relates with the fact that several relatively large-scale scientific research experiments have already been conducted over the last two decades (Boyd, 2013; Boyd et al., 2007). Therefore the effectiveness of this geoengineering method not only relies upon simulation models of ocean biogeochemistry and iron fertilisation, but also upon experimental and observational data (Vaughan and Lenton, 2011).

The second unique aspect of this geoengineering method stems from the first, for it refers to the efforts that have been conducted to address ocean fertilisation experiments at an international regulatory level. Indeed, the political controversy and public attention that surrounded some of the above mentioned OIF field experiments[29] intensified those efforts and help explain why, to date, ocean fertilisation is the geoengineering method subject to the most detailed regulatory framework[30] (Bodle, 2013).

The experiments that have been conducted so far have not been able to demonstrate the practical effectiveness of this approach and show that it is

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[27] For a detailed description of the biologic pump process see De La Rocha CL. (2003) The Biological Pump. In: Elderfield H (ed) *Treatsie on Geochemistry - The Oceans and Marine Geochemistry.* NY: Elsevier, 84-111.

[28] This CDR method draws upon the *'Iron Hypothesis'* formulated by John H. Martin Martin JH. (1990) Glacial-interglacial CO2 change: The Iron Hypothesis. *Paleoceanography* 5: 1-13., according to which the "*productivity in today's southern ocean* (7.4×10^{13}g yr^{-1}) *is limited by iron deficiency, and hence the phytoplankton is unable to take advantage of the excess surface nitrate/phosphate that, if used, could result in total southern ocean new production of* $2^{-3} \times 10^{15}$ *g C* yr^{-1}".

[29] LOHAFEX was the largest OIF field experiment conducted so far. From January to March 2009 scientists from the German Alfred Wegener Institute for Polar and Marine Research and from the Indian Institute of Oceanography released six tons of dissolved iron over a 300-square-kilometre section of the southern Atlantic Ocean. The experiment attracted extreme opposition from environmental groups and non-governmental organisations and, for a short period, the German government put a stop to the venture, before allowing it to proceed.

[30] Ocean fertilisation experiments are now regulated under the London Convention and London Protocol. See IMO Marine geoengineering including ocean fertilization to be regulated under amendments to international treaty (October 18, 2013)
http://www.imo.org/OurWork/Environment/LCLP/EmergingIssues/geoengineering/Pages/default.aspx

remarkably difficult to increase the sinking flux of carbon to the deep ocean (Buesseler K.O. et al., 2004; Martin et al., 2013). In addition, modelling studies indicate that even if global iron fertilisation could be deployed for a century, the potential role of ocean fertilisation in carbon sequestration would be modest, lowering it by, at most, around 30 ppm (Vaughan and Lenton, 2011). Lastly, because all ocean fertilisation methods involve a wide range of inextricably linked changes in ocean physics, chemistry, biology, and ecology, the possible side effects on both marine and adjacent terrestrial ecosystems remain largely unknown[31]. The indented and unintended biochemical and ecological impacts will never be local, spreading over large areas by ocean circulation. This makes the verification and assessment processes of these methods particularly difficult (The Royal Society, 2009; Boyd, 2013).

- **3. Direct air capture** - This CDR method refers to a chemical process by which a pure CO_2 stream is produced by capturing CO_2 from ambient air. The direct air capture (DAC) process comprises two main phases: absorption and regeneration. The absorption phase refers to the process of dissolving the CO_2 contained in the atmosphere into solution or onto a solid sorbent. The regeneration phase refers to producing a concentrated stream of CO_2 from the means used for absorption (Zeman and Keith, 2008). The resulting stream of pure CO_2 is then used or sequestered in geological reservoirs or the deep ocean[32], while the sorbent is regenerated and the CO_2-depleted air is returned to the atmosphere (Socolow et al., 2011).

  Although not yet tested on a large-scale, several conceptual designs of DAC systems have already been proposed in the literature. According to the characteristics of the sorbent surface, they are usually subdivided into three

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[31] Including the possible disruption in the lowest links of the food chains and the accelerated acidification in the deep ocean Cao L and Caldeira K. (2010) Can ocean iron fertilization mitigate ocean acidification? *Climatic Change* 99: 303-311.

[32] An alternative disposal or re-use strategy is to convert the CO_2 into a transport fuel by combining it with hydrogen Zeman FS and Keith DW. (2008) Carbon neutral hydrocarbons. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* 366: 3901-3918.

main categories (The Royal Society, 2009; IPCC, 2013b): (i) adsorption on solids (Li et al., 2010; Gray et al., 2008; Lackner, 2009; Lackner, 2010; Lackner et al., 2012; Choi et al., 2011) (ii) absorption into highly alkaline solutions (Stolaroff et al., 2008; Mahmoudkhani and Keith, 2009), and (iii) absorption into moderate alkaline solution with a catalyst (Bao and Trachtenberg, 2006).

Although the DAC process described above seems to have minimal undesirable consequences (except those associated with handling process materials or chemicals) (GAO, 2011), some concerns have been raised about the energy penalties in capturing and compressing CO_2 and its subsequent long-term storage (Vaughan and Lenton, 2011; The Royal Society, 2009). These and other limitations (as the thermodynamic barrier due to the low concentration of CO_2 in ambient air and the estimated high costs involved in the DAC process) result in substantial uncertainties surrounding the scalability of direct air capture technologies.

- **4. Bioenergy with Carbon Capture and Storage (BECCS)** - Bioenergy with carbon capture and storage draws upon existing technologies for bioenergy[33] and for carbon capture and storage (CCS)[34], inheriting both their advantages and

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[33] The Food and Agriculture Organization of the United Nations (FAO) defines bioenergy as "the energy derived from all forms of biomass, including forest biomass" Mabee WE and Saddler JN. (2007) *Forests and energy in OECD countries,* Rome: FAO. Bioenergy has the potential to have a large contribution towards energy needs in the immediate future - according to the International Energy Agency (IEA), bioenergy offers the potential to meet 50% of our world energy needs in the 21st century. However, there are still important constraints on the development and diffusion of appropriate bioenergy technologies, such as: (i) tenure and land management constraints stemming from land ownership/land rights; (ii) competition for use of productive land between bioenergy and food crops; (iii) impacts on biodiversity resulting from large-scale production of biomass feedstocks, (iv) potential negative impacts on communities; (v) environmental impacts associated with biomass conversion processes; and (v) market-place and economic problems (the potential bioenergy markets are dominated by well established technologies and influenced by the convenience of an existing supply network, and bioenergy applications remain currently too expensive to compete with fossil fuels) Lwin K. (2004) Policy Options and Strategies for Market Development of Biomass: an Asian-Pacific Perspective. In: Sims REH (ed) *Bioenergy Options for a Cleaner Environment: in Developed and Developing Countries.* Amsterdam, The Netherlands: Elsevier B.V., 141-160, Gough C and Upham P. (2011) Biomass energy with carbon capture and storage (BECCS or Bio-CCS). *Greenhouse Gases: Science and Technology* 1: 324-334.

[34] Carbon capture and storage (CCS) is a process that consists of separating and capturing CO_2 from large power stations, transporting it to a storage site, and isolating it from the atmosphere - mainly in depleted oil or gas fields or in saline formations - for very long periods of time (on the order of several centuries to millions of years) IPCC. (2005) *IPCC Special Report on Carbon Dioxide Capture and Storage. Prepared by*

disadvantages (The Royal Society, 2009). The combination of this pair of technologies leads to an energy system with negative emissions characteristics, holding out the prospect of reducing current atmospheric carbon dioxide concentrations to pre-industrial levels (Gough and Upham, 2011; Read, 2008; Read and Lermit, 2005; Obersteiner et al., 2001). For Read and Lermit (2005), a portfolio based on BECCS technologies, yielding a negative-emissions energy system, "*may be seen not only as benign geoengineering, free of the risks associated with other geoengineering, but also as one of the keys to being prepared for ACC* [Abrupt Climate Change"].

BECCS covers a variety of biomass and biofuel production pathways involving numerous sources of biomass raw materials (derived from wastes or from dedicated land used for energy plantations or annual energy crops), followed by capture of the CO_2 produced in the fermentation process and in combustion at power plants, transport of the CO_2 to the storage site, and long-term underground storage (Vaughan and Lenton, 2011; Read and Lermit, 2005; Gough and Upham, 2011).

Rhodes and Keith (Rhodes and Keith, 2005) explored the possibility of integrating or combining the three technological approaches that have been advanced for CCS[35] with biomass energy systems and suggested the feasibility and potential of

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Working Group III of the Intergovernmental Panel on Climate Change, Cambridge, United Kingdom and New York, NY, USA Cambridge University Press, Watson RT and Aquino AR. (2010) The Road Forward. In: Schneider SH, Rosencranz A, Mastrandrea MD, et al. (eds) *Climate Change Science and Policy.* Washington D.C.: Island Press, 423-431.The International Energy Agency (IEA) estimates that CCS could contribute towards one sixth of CO_2 emissions reductions required by 2050, and 14% of the cumulative emissions reductions through 2050 against a business-as-usual scenarioIEA. (2013) *Technology Roadmap: Carbon Capture and Storage 2013,* Paris: International Energy Agency. However CCS technologies have limitations that arise from three main barriers: (i) the high energy requirements to capture, run the coal gasification plants and compress the CO_2 before it can be injected into the ground (iii) the costs involved in these activities (most estimates shows that CCS adds around 25% to 40% to the cost of a power plant Montgomery SL. (2010) *The Powers That Be: Global Energy for the Twenty-first Century and Beyond,* Chicago: The University of Chicago Press.), and (iii) the lack of safe and permanent reservoirs to store large volumes of CO_2 House of Commons Science and Technology Committee. (2006) Meeting UK Energy and Climate Needs: The Role of Carbon Capture and Storage. First Report of Session 2005-06. London: House of Commons Science and Technology Committee , Parker CL and Shapiro SM. (2008) *Climate Chaos: Your Health at Risk, What You Can Do to Protect Yourself and Your Family,* Westport, CT: Praeger.

[35] Three main technologies have been proposed to attain the goal of CCS technologies (Cf. footnote 34): (i) post-combustion capture, where CO_2 is captured from the flue gases produced during combustion; (ii) oxyfueling, where combustion occurs in pure oxygen and CO_2 is separated by condensing water from the

the following biomass-CCS routes: (i) biological processing with capture of CO_2 by-products to produce liquid fuels; (ii) biomass gasification with shift and CO_2 separation to produce hydrogen; and (iii) biomass combustion to produce electricity with CCS—either by oxyfuel or post-combustion capture.

According to Read and Parshotam (Read and Parshotam, 2007; Read, 2008), a Biomass-Biosphere Carbon Stock Management (BCSM) programme, where an initial transition period to a large biofuel energy system would be followed by the integration of bioenergy with CCS, could theoretically lead to pre-industrial atmospheric CO_2 levels within a few decades. This holistic strategy assumes in its first stage the creation of a strategic reserve stock of biomass raw material in new plantation forests[36] and the growth of a large-scale, global bio-energy market involving world trade in bio-fuels. The second stage would involve linking CO_2 capture and sequestration to bio-energy, yielding a negative emissions energy system. Hence, with low-cost CO_2 sequestration from fermentation starting in 2020 and CO_2 capture from flue gases in 2025, up to 50 Pg C could be sequestered by 2035 and 298 Pg C by 2060 (Read and Parshotam, 2007). Taking this scenario as an upper estimate, Lenton and Vaughan calculated that 124 PgC (58ppm) would be removed from the atmosphere in 2050 and 771 PgC (186 ppm) in 2100. This would lead to a radiative forcing of $\approx -0.60 \text{ W m}^{-2}$ and $\approx -1.99 \text{W m}^{-2}$ in 2050 and 2100 respectively (Lenton and Vaughan 2009).

These optimistic estimates rely heavily on assumptions about (i) the basic logistics for supply of feedstocks, (ii) technological progress with biomass

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exhaust; and (iii) pre-combustion capture, which refers to the removal of the fuel embedded carbon in hydrocarbons to produce hydrogen, which then combusts in a gas turbine, emitting a relative pure stream of water vapour Herold J. (2008) *Microeconomic Analysis of Investment Incentives Under Emission Control. The case of carbon capture and storage*: GRIN Verlag, Baker E, Nemet G and Rasmussen P. (2012) Modeling the Costs of Carbon Capture. In: Zheng QP, Rebennack S, Pardalos PM, et al. (eds) *Handbook of CO_2 in Power Systems.* Springer Berlin Heidelberg, 349-372, Rhodes JS and Keith DW. (2005) Engineering economic analysis of biomass IGCC with carbon capture and storage. *Biomass and Bioenergy* 29: 440-450.

[36] "Before 2035, the main out-of-atmosphere stock arises from the creation of a strategic reserve of biomass raw material through the development of 1bHa of new forest plantations. An area equal to about half the forest area lost since the beginning of industrialisation" Read P and Parshotam A. (2007) Holistic greenhouse gas management: mitigating the threat of abrupt climate change in the next few decades (with reviewers comments and author rejoinders). *Institute of Policy Studies Working Paper 07/1*. (accessed 02/06/2014).

production and conversion, (iii) greater energy efficiency, (iv) increased use of non-fuel renewables, (iv) accessible and efficient CCS infrastructures, (v) costs of operation, (vi) price trajectories of oil, timber, food and other co-produced outputs, (vii) growth of a large-scale, global bio-energy market involving world trade in bio-fuels, and (viii) availability of CO_2 storage (among others). Therefore, if such a strategy were to be implemented, these assumptions would have to be supported by strong political, regulatory, industrial, and social will.

BECCS technology has not been tested on an industrial scale[37], but is commonly included in Integrated Assessment Models and future scenarios that aim to achieve low CO_2 concentrations[38]. Accordingly, and despite the limited evidence on the potential for large-scale deployment of these technologies and their unpredictable (but almost certain) side effects and long-term consequences on a global scale, the Representative Concentration Pathway (RCP) scenarios used as a basis for future projections in the AR5 already include this geoengineering option[39]. The political implication of this is clear, as recognised by IPCC Working Group II (WGII): "the increasing dependence of pathways on CDR options reduces the ability of policymakers to hedge risks freely across the mitigation technology portfolio" (IPCC, 2014a).

- **5. Biochar and biomass burial methods** - Sequestration of biomass and biochar have been proposed as a method for intervening in the global carbon cycle . The

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[37] However, some small dedicated BECCS projects are currently in the construction or operation phase (located in the USA and the Netherlands), all of which are ethanol production facilities Gough C and Upham P. (2011) Biomass energy with carbon capture and storage (BECCS or Bio-CCS). *Greenhouse Gases: Science and Technology* 1: 324-334.

[3838] In fact, long-term mitigation scenarios typically rely on the availability and widespread use of BECCS and large-scale afforestation in the second half of the century IPCC. (2013b) *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change,* Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

[39] To achieve the RCP2.6 CO_2 peak and decline the IMAGE integrated assessment model simulates widespread implementation of BECCS technology to achieve globally negative emissions after around 2080 (Cf. AR5 WGI Section 6.4.3). RCP4.5 also assumes some use of BECCS to stabilise CO_2 concentration by 2100.

aim of these CDR methods is to increase the net primary productivity (NPP)[40] and store a larger fraction of the biomass and biochar produced into ecosystem carbon pools with long turnover times (The Royal Society, 2009; IPCC, 2013b).

Biomass has long been recognised as a potential source of renewable energy that could reduce the dependency on fossil fuels and other non-renewable resources (Demuynck et al., 1984). In addition, biomass can act as a means of offsetting emissions by sequestering carbon in terrestrial ecosystems. Indeed, feedstock biomass that otherwise would not be used for habitat preservation, crops, or energy production could be buried in the land and deep ocean to slow the rate at which CO_2 is released to the atmosphere (Bracmort et al., 2010).

As biomass is one of the most contested accessible resources, a fundamental tension exists between utilising biomass for CDR and using it to attain one of the other ends mentioned above (Haszeldine and Scott, 2014). In addition, the methods involving burying biomass in the land or deep ocean require additional energy consumption for transport, burying, and processing and may disrupt growth, nutrient cycling and the viability of the ecosystems involved (The Royal Society, 2009). For these reasons it is unlike that biomass for sequestration could make a large contribution to a geoengineering approach aimed at enhancing the global carbon sink.

Carbon capture via biochar involves producing from pyrolysis[41] of plants and organic waste[42] a charcoal-like substance (called biochar) high in organic carbon

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[40] Net primary productivity (NPP) is defined as "the uptake of CO_2 by photosynthesis less that released by autotrophic (plant) respiration. This primary production provides the energy sources and substrates for virtually all major ecosystems on Earth" Beerling DJ and Butterfiel NJ. (2012) Plants and Animals as Geobiological Agents. In: Knoll AH, Canfield DE and Konhauser KO (eds) *Fundamentals of Geobiology.* Chichester, UK: Wiley-Blackwekk, 188-204.

[41] Pyrolysis processes deal with the rapid thermal decomposition of organic material (in this case biomass) at high temperatures in the absence of oxygen. The decomposition process produces both biochar and bio-oil. The bio-oil can be converted to a biofuel after a costly conversion process, and the biochar can serve as bio-sequester (i.e. atmospheric carbon capture and storage).

[42] In addition to plant biomass, there is a wide range of other potential biochar feedstocks, including waste materials such as poultry litter and sewage sludge Chan KY and Xu Z. (2009) Biochar: Nutrient Properties and Their Enhancement. In: Lehmann J and Joseph S (eds) *Biochar for Environmental Management.* London: Earthscan, 67-84, Shackley S, Sohi S, Ibarrola R, et al. (2013) Biochar, Tool for Climate Change Mitigation and Soil Management. In: Lenton TM and Vaughan NE (eds) *Geoengineering Responses to Climate Change.* Springer New York, 73-140.

and largely resistant to decomposition. The resultant biochar could then be buried underground where it would remain for a centennial to millennial timescale, acting as a recalcitrant carbon reservoir (Vaughan and Lenton, 2011). In addition to the potential for carbon sequestration, biochar amendment of soil could improve soil fertility and crop productivity, enhancing nutrient retention and bioavailability (Chan and Xu, 2009; Shackley et al., 2013).

Estimates of the global potential for enhanced primary productivity over land, the residence time of carbon converted to biochar, and the additional effect of biochar on soil productivity are very uncertain. This is so because the potential of any specific method will be severely constrained by competing land needs (e.g., agriculture, biofuels, urbanization and conservation) and sociocultural considerations (The Royal Society, 2009; IPCC, 2013b).

Notwithstanding, based on published projections of the use of renewable fuels in the year 2100, Lehmann et al. (2006) estimated that biochar sequestration would potentially yield an amount of 5.5–9.5 PgC yr^{-1} if pyrolysis were to be used. The maximum potential sequestration of 9.5 PgC yr^{-1} would exceed current anthropogenic emissions from fossil fuels (5.4 PgC yr^{-1} in 2006). Such fluxes assume that there will be enormous growth in the resources devoted to the production of biofuels, and that some large fraction of this carbon would be converted to biochar. However, the use of crops for renewable fuels on such a scale would very likely conflict with the use of agricultural land for the production of food and/or biofuels (The Royal Society, 2009; Vaughan and Lenton, 2011). Some concerns have also been raised that inappropriately applied incentives to encourage biochar might increase the cost and reduce the availability of food crops.

International law does not specifically address the production of biochar and biomass, or the biochar and biomass burial methods here discussed. Nevertheless, as these methods entail considerable large-scale land use changes, the current international legal regime for the protection of biodiversity, ecosystems and habitats may indirectly impose restrictions to large scale deployment of these geoengineering options (Bodle, 2013).

- **6. Afforestation/Reforestation** - The conversion of land from its natural state has had profound effects on terrestrial ecosystems and Earth system dynamics over the past three centuries (Turner II et al., 1990)[43]. The effects of land use and land-cover change (LULCC) on the Earth systems include alterations in the surface albedo, distribution of sources and sinks of carbon over the land surface, flux of carbon between terrestrial ecosystems and the atmosphere, radiative forcing, surface roughness, atmospheric turbulence, rates of evapotranspiration, latent heat flux, etc. (Hurtt et al., 2006; Pielke et al., 2011; Adams, 2008).

  The cumulative net CO_2 emissions from land use changes between 1750 and 2011 are estimated at approximately 180 ± 80 PgC (IPCC, 2013b)[44]. Two-thirds to three-quarters of the total carbon losses to the atmosphere due to land-use change resulted from the conversion of forests to cropland or other land uses (House et al., 2002; Canadell and Raupach, 2008). Assuming that the total carbon loss resulted from forest conversion could be restored to the terrestrial biosphere, an order of magnitude of the upper potential of afforestation/reforestation[45] would be ≈120 to 135 PgC. This is an extreme estimate that does not take into account the "rebound effect"[46], economical

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[43] Hurtt et al. Hurtt GC, Frolking S, Fearon MG, et al. (2006) The underpinnings of land-use history: three centuries of global gridded land-use transitions, wood-harvest activity, and resulting secondary lands. *Global Change Biology* 12: 1208-1229. estimate that 42 to 68% of the global land surface was impacted by land use activities (crop, pasture, wood harvest) during the 1700–2000 period.

[44] The global net CO_2 emissions from land use change are estimated at 1.4, 1.5 and 1.1 PgC yr^{-1} for the 1980s, 1990s and 2000s, respectively Houghton RA, House JI, Pongratz J, et al. (2012) Carbon emissions from land use and land-cover change. *Biogeosciences* 9: 5125-5142. The cumulative net CO_2 emissions from land use change have been dominated by deforestation and other land use change in the mid-northern latitudes prior to 1980s, and in the tropics since the 1980s, largely from deforestation in tropical America and Asia with smaller contributions from tropical Africa IPCC. (2013b) *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change,* Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

[45] "Afforestation is the direct human-induced growth of forest on land that has not historically been forested. Reforestation is the direct human-induced conversion on nonforested land to forest land that had been previously converted from forest to other uses" Caldeira K, Bala G and Cao L. (2013) The science of geoengineering. *Annual Review of Earth and Planetary Sciences.* 231-256.

[46] When CO_2 is removed from the atmosphere, the CO_2 concentration gradient between atmospheric and land/ocean carbon reservoirs is reduced, leading to a reduction or reversal in subsequent inherent rate of removal of CO_2 from the atmosphere by natural carbon cycle processes on land and ocean. This is what is

factors, competing land needs or other social and political considerations. However, over the last decades efforts have been undertaken to obtain more realistic estimates of the upper limit of CO_2 sequestration by global afforestation and reforestation activities[47] (Nilsson and Schopfhauser, 1995; IPCC, 2000; House et al., 2002; Canadell and Raupach, 2008). House el al. (2002) estimated that the maximum feasible reforestation and afforestation activities over the next 50 years would result in a reduction in CO_2 concentration of about 15-30 ppm by the end of the century. A more optimistic estimate is that an irrigated afforestation project in the Sahara and Australian Outback could sequester each year amounts of atmospheric CO_2 at least equal to that released from burning fossil fuel (Ornstein et al., 2009). It is under these seemingly disparate estimates that large-scale afforestation and reforestation projects have been proposed as a near-term route to reduce atmospheric CO_2 concentrations and a strategy to control human-induced global warming (and therefore seen as a form of geoengineering[48]). Despite the uncertainties surrounding the long-term effectiveness of these CDR methods under continued changes in atmospheric CO_2, large afforestation/reforestation programmes are already underway at a global scale, with around 264 million hectares having been planted in recent decades (FAO, 2010; Lenton, 2014; Vaughan and Lenton, 2011). Like any large-

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known as "rebound effect" IPCC. (2013a) Annex III: Glossary. In: Stocker TF, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (ed) *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press, 1447-1466. According to the last IPCC WGI assessment report "The ‘rebound effect’ in the natural carbon cycle *is likely* to diminish the effectiveness of all the CDR methods" IPCC. (2013b) *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change,* Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

[47] The maximum amount of carbon that might be sequestered by global afforestation and reforestation activities for the 55-year period 1995-2050 was estimated at 60-87 Gt C, with about 70 percent in tropical forests, 25 percent in temperate forests, and 5 percent in boreal forests IPCC. (2000) *Land Use, Land-Use Change, and Forestry,* Cambridge, UK: Cambridge University Press,.

[48] Given the distinction made between mitigation and geoengineering (See for instance Keith DW. (2000) Geoengineering the climate: history and prospect. *Annual Review of Energy and the Environment* 25: 245-284, Vaughan N and Lenton T. (2011) A review of climate geoengineering proposals. *Climatic Change* 109: 745-790, The Royal Society. (2009) Geoengineering the climate: science, governance and uncertainty. London: The Royal Society, 98.), large-scale forest management for the purpose of removing atmospheric CO_2 is considered a form of geoengineering, in contrast to avoided deforestation, which prevents anthropogenic CO_2 and is therefore a mitigation action.

scale transformation of land use patterns, afforestation/reforestation can lead to unintended environmental and socioeconomic impacts. Concerns include changes in surface albedo, changes in evapotranspiration that have the potential to affect cloud cover and reflectivity, ecosystem-carbon loss over time through erosion and the degradation of soil-carbon pools, loss of biodiversity, reduced stream flows, decreased food security, and intensification of conflicts with current strategies for conservation and habitat management (Keith, 2002; Lenton, 2014; Vaughan and Lenton, 2011; Haszeldine and Scott, 2014).

- **7. Land-based enhanced weathering** - Although the total magnitude of natural weathering-associated carbon fluxes is smaller than other fluxes in the modern carbon cycle (Peters et al., 2012), these weathering reactions play an important role in regulating climate (Hartmann et al., 2013; Hartmann et al., 2009). The removal of CO_2 by chemical weathering[49] ranges from 0.22 to 0.29 PgC yr^{-1} (Gaillardet et al., 1999; Hartmann et al., 2009). The rate at which these chemical reactions take place is currently too small to offset the rate at which fossil fuel CO_2 is being emitted[50]. For this reason, CO_2 sequestration by the weathering of silicate and carbonate minerals has long been neglected in the global climate change debate (Schuiling, 2013). Over the last few years, however, it has been suggested that artificially increasing by large factors the mineral weathering rates could effectively accelerate the rate of transfer of carbon out of the atmosphere, thus leading to a gradual decrease in atmospheric CO_2 concentrations (Schuiling, 2013; Hartmann et al., 2013). The basic understanding of how silicate and

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[49] Chemical weathering is the process by which individual minerals are dissolved or transformed to new minerals. This process occurs due to several chemical reactions initiated by water or acids in the soil solution. The dominant type of chemical weathering is by carbonic acid (H_2CO_3) formed in soil from water (H_2O) and carbon dioxide (CO_2). Chemical weathering plays an important role in global biochemical cycles. Of particular interest is the role of chemical weathering in regulating climate through its effects on the drawdown of atmospheric CO_2. Bonan G. (2008) *Ecological Climatology: Concepts and Aplications,* Cambridge, UK: Cambridge University Press, Allen PA and Allen JR. (2013) *Basin Analysis: Principles and Application to Petroleum Play Assessment,* Chichester, UK: Wily-Blackwell.

[50] In 2011, fossil fuel emissions were 9.5 [8.7 to 10.3] PgC IPCC. (2013b) *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change,* Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

carbonate weathering acts to drawdown atmospheric CO_2 is relatively well known[51] and a number of CDR proposals aimed at increasing the rates of these reactions have already been suggested.

For instance, Shuiling and Krijgsman (2006) suggested that probably the cheapest way to sequester large volumes of CO_2 would be by spreading large volumes of fine-powdered olivine or crushed basalt to farmland or future woodland threatened by acid rain. This would not only contribute to reduce current levels of CO_2 in the atmosphere, but would also provide an effective way of counteracting the effect of acid rain on forests, and of improving the quality of the forest soil. In the idealised case where olivine could be distributed as a fine powder over all land areas of the humid tropics, potential removal rates of up to 1 PgC yr^{-1} have been estimated. This estimate considers the limitation by the saturation of silicic acid and assumes a complete dissolution of all distributed olivine (Köhler et al., 2010).

Alternatively, it has suggested that the rate of the reaction of CO_2 with basic minerals (such as basalts and olivine) could be enhanced through methods of in situ mineral carbonation that exploit the chemical potential energy inherent in tectonic exposure of mantle peridotite at the Earth's surface. According to Kelemen and Matter (Kelemen and Matter, 2008; Kelemen et al., 2011) this method could consume >1 billion tons of CO_2 per year in Oman alone, affording a low-cost, safe, and permanent method to capture and store atmospheric CO_2.

Besides the geoengineering potential of enhanced weathering, some "collateral benefits" of this CDR method have already been identified, including: (i) increase the alkalinity of the soil and water on a global scale, which would reduce CO_2 induced acidification of the terrestrial and marine environments (ii) accelerate nutrient supply to terrestrial ecosystems, improving soil productivity, and thus leading to greater sequestration of CO_2 in terrestrial biomass (The Royal Society, 2009; Schuiling, 2013; Hartmann et al., 2013).

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[51] See for instance Hartmann J, West J, Renforth P, et al. (2013) Enhanced Chemical Weathering as a Geoengineering Strategy to Reduce Atmospheric Carbon Dioxide, a Nutrient Source and to Mitigate Ocean Acidification. *Reviews of Geophysics*.

Although agricultural practices that have long been in use on a small scale (such as tilling, mineral fertilization, or liming to adjust soil pH.) offer promising prospects regarding the ability of land-based enhanced weathering to drawdown atmospheric CO_2 concentrations, it is almost impossible to predict how much the fluxes of carbon and nutrients between compartments in the Earth System would change following large-scale deployment of this geoengineering method (Hartmann et al., 2013). Moreover, the application of large quantities of rock powder to the land surface would incur significant changes, both predictable and unpredictable, to the entire ecosystem. In addition, to have a significant geoengineering impact, most of these proposals involve large mining and transportation activities, which require considerable energy inputs.

Solar Radiation Management

The second major geoengineering approach – solar radiation management (SRM) – seeks to reduce the amount of incoming short-wave solar radiation received by Earth's atmosphere, surface and oceans by deflecting sunlight, or by increasing the reflectivity of the atmosphere, clouds or Earth's surface (i.e., enhancing the planetary albedo) (IPCC, 2013b; The Royal Society, 2009; Vaughan and Lenton, 2011). SRM methods proposed to produce these effects can be subdivided into three subcategories, according to the scale in which they operate, namely: i) space-based techniques, operating in outer space; ii) atmospheric-based techniques, operating in the atmosphere, and iii) surface-based techniques, operating in the Earth's surface (Humphreys, 2012). Contrary to what happens with CDR methods, SRM approaches do not address the very root cause of human-induced climate change; that is, a perturbation of the global carbon cycle through the increased concentration of CO_2 in the atmosphere (Lenton and Vaughan, 2013; Richardson et al., 2011). Indeed, all SRM techniques would leave the carbon cycle largely untouched in the first instance and would also do nothing to slow ocean acidification (Hartmann et al., 2013; The Royal Society, 2009). Although remaining uncertainties in important climate processes underlying SRM methods, relative scarcity of studies, and differences in model physics and experimental design preclude a comprehensive assessment of the efficacy and side effects of SRM, the IPCC concluded in its last assessment report that "SRM in concert with aggressive CO_2 mitigation might conceivably help avoid transitions across climate thresholds or tipping points that would be unavoidable otherwise" (IPCC, 2013b: 635).

The following is a brief description of the most widely discussed SRM methods, as illustrated in Figure 8.

Figure 8 - Illustration of the most widely discussed Solar Radiation Management methods. (Source: GAO, 2010: 11).

1. Space-based reflective mirrors - Perhaps one of the most extravagant geoengineering options is the positioning of sun-shields in space to reflect or deflect incoming solar radiation[52]. The basic underlying principle is that placing reflectors or scatters between the Earth and the Sun could significantly diminish the amount of solar radiation incident on the top of the Earth's atmosphere. The amount of reduction in solar radiation proposed is close to that required to offset the global warming induced by increased greenhouse gases (Lunt, 2013; Vaughan and Lenton, 2011). Accordingly, it has been assumed that to offset a doubling of atmospheric CO_2 concentrations above preindustrial levels[53] a decrease in incoming solar radiation of roughly 1.8 percent would be required (Angel, 2006; Govindasamy and Caldeira, 2000). Numerous techniques have been proposed to achieve this goal, all of them centred on fabricating and deploying a single sunshade superstructure, or an array of millions of tiny reflectors or refractors (McInnes, 2010; Lunt, 2013). Some involve fabricating a sunshade on Earth and transporting it to space, while others consist in building a sunshade out in space from materials available on asteroids (Lunt, 2013). Several options have been considered regarding the location of the sunshade along the Sun–Earth line.

One proposal suggested installing 55.000 mirrors (each with an area of 100 km^2) in random orbits (National Academy of Sciences, 1992). An alternative suggestion is to create an artificial ring of passive scattering particles with a mass of order 2 x 10^9 tonnes in the Earth's orbit (Mautner, 1991; McInnes, 2002). Pearson et al (2006) proposed to create an artificial planetary ring above the Earth's equatorial orbit (similar to Saturn's B ring), composed of passive particles (derived from the Earth, moon, or asteroids) or controlled spacecraft with parasols. This flat ring from 1.2 to 1.6 Earth radii would shade mainly the tropics, moderating climate extremes, and providing sufficient opacity to reduce insolation by 1.6 percent.

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[52] According to Lunt Lunt DJ. (2013) Sunshades for Solar Radiation Management. In: Lenton TM and Vaughan NE (eds) *Geoengineering Responses to Climate Change.* Springer New York, 9-20., one of the first references to the use of this technology can be found in the James Oberg's book *New Earths: Restructuring Earth and Other Planets* Oberg JE. (1981) *New Earths: Transforming Other Planets for Humanity,* Harrisburg, PA: Stackpole Books. However, as the title of the book suggests, the idea of placing sunshades in space was not intended to alter the Earth's climate, but rather modifying the climates of extraterrestrial planets, with the aim of making them habitable.

[53] The pre-industrial level of CO_2 in the atmosphere is estimated to have been 280 ppm. A doubling of CO_2 would then be 560 ppm.

An alternative to placing sunshades in low Earth orbit is to place them near the “first Lagrange point” (also known as the “L1 point”), which is an equilibrium point directly between the Earth and sun, about 1 .5 million kilometres above the planet, where the forces pulling an object toward the Sun are exactly balanced by the forces pulling an object toward Earth (The Royal Society, 2009; Caldeira et al., 2013; Lunt, 2013)[54]. Angel (2006) suggested that a cloud of scattering particles positioned near the Earth–sun inner Lagrange point (L1) could block 1.8 percent of the incoming solar radiation. This sunshade would be manufactured entirely on Earth and then launched to space, and it would take the form of many small autonomous spacecraft, or ‘‘flyers’’. These flyers would weigh a gram each, be launched in stacks of 800,000, and remain for a projected lifetime of 50 years within a 100,000- km-long cloud.

All these space-based techniques involve major uncertainties regarding costs, effectiveness, timescales of implementation, and potential side-effects (The Royal Society, 2009; Govindasamy et al., 2002). Moreover, deployment of such space-based proposals could prove extremely changeling, both in technological and economic terms. Because these proposals would require an unprecedented scale of production, with extremely high costs of deployment, it would take several decades before any of them could be fully implemented (The Royal Society, 2009; Caldeira et al., 2013; Lunt, 2013; McInnes, 2010). For these reasons - not to mention other legal[55], moral, and ethical considerations - "it

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[54] According to Lunt Lunt DJ. (2013) Sunshades for Solar Radiation Management. In: Lenton TM and Vaughan NE (eds) *Geoengineering Responses to Climate Change.* Springer New York, 9-20., however, a sunshade placed at the L1 point is unstable, in that if it is displaced slightly due to the pressure exerted by the Sun’s radiation itself, it will be accelerated further in the same direction. Therefore Lunt suggests that a more suitable location for a sunshade would be slightly closer to the Sun than the L1 point, allowing the radiation pressure to balance the offset in gravitational attraction.

[55] As stated in the Working Group III contribution to the IPCC's Fifth Assessment Report the 1967 Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies (United Nations, 2002) may apply to the use of sun-deflecting mirrors in space Stavins R, Zou J, Brewer T, et al. (2014) International Cooperation: Agreements and Instruments. In: Edenhofer O, Pichs-Madruga R, Sokona Y, et al. (eds) *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge, United Kingdom and New York, NY, USA.: Cambridge University Press.

seems unlikely that a giant sunshade will be launched into space any time soon" (Lunt, 2013: 19).

- **2. Stratospheric aerosol injection** - Perhaps the most widely discussed geoengineering option is the injection of sulphate aerosols into the lower stratosphere to mimic the cooling effect caused by large volcanic eruptions.

  One of the first proposals was made by Mikhail Budyko, a Russian climatologist, in 1974 (Budyko, 1977). Inspired by the cooling effect of Mount Tambora's eruption[56], Budyko suggested that burning some 100.000 tons of sulphur per year could generate an artificial cloud of 600.000 tons of sulphuric acid with potential to reduce the Earth's temperature by several degrees (Fleming, 2010; Keith, 2000). This idea was recently revived by Nobel Laureate Paul Crutzen, who wrote an influential editorial essay in the Journal *Climatic Change* (2006) calling for active research into geoengineering and, particularly, into the effectiveness and possible side effects of stratospheric albedo modification schemes[57]. Since then several proposals have been suggested to artificially increase aerosol levels in the stratosphere, and thus enhance the planetary reflectivity (albedo) (Brühl et al., 2013; Jones et al., 2010; Kalidindi et al., 2014; McCusker et al., 2012; Rasch et al., 2008; Tuck et al., 2008; Volodin et al., 2012; Davidson et al., 2012; Jones et al., 2011; Pitari et al., 2014; Kravitz et al., 2012).

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[56] The eruption of Tambora in 1815 (the largest volcanic eruption ever recorded) sent tons of volcanic ash into the atmosphere, profoundly altering global weather patterns. The year after the eruption is known as "the year without summer" in reference to the global cooling caused by the eruption Klingaman W and Klingaman N. (2013) *The Year Without Summer: 1816, and the Volcano That Darkened the World and Changed History,* New York: St. Martin's Press.

[57] Crutzen's editorial reignited the debate about whether we should explore geoengineering solutions Schneider SH. (1996) Geoengineering: Could— or should— we do it? *Climatic Change* 33: 291-302. Because this essay helped to legitimise geoengineering research Thornes JE and Pope FD. (2014) Why do we need Solutions to Global Warming? In: Harrison R and Hester R (eds) *Geoengineering of the Climate System.* Cambridge, UK: The Royal Society of Chemistry, 1-21. the arguments therein presented have been subject to critical scrutiny Gardiner SM. (2010) Is 'arming the future' with geoengineering really the lesser evil? Some doubts about the ethics of intentionally manipulating the climate system. In: Gardiner SM, Caney S, Jamieson D, et al. (eds) *Climate Ethics, Essential Readings.* New York: Oxford University Press, 284-312, Gardiner SM. (2011b) *A Perfect Moral Storm: The Ethical Tragedy of Climate Change*: Oxford University Press, Moellendorf D. (2014) *The Moral Challenge of Dangerous Climate Change: Values, Poverty, and Policy,* New York: Cambridge University Press, Hamilton C. (2013a) Ethical Anxieties about Geoengineering. In: Sandler RL (ed) *Ethics and Emerging Technologies.* Hampshire: Palgrave Macmillan, 439-455.

A stratospheric aerosol injection scheme designed to counteract the radiative forcing due to a doubling of atmospheric CO_2 would require an average global increase in atmospheric albedo of 0.012 (Vaughan and Lenton, 2011; Vaughan et al., 2009). The way this could be accomplished would depend on the types of aerosol used to scatter sunlight back to space, the particle size, the methods by which the aerosols would be placed in the stratosphere[58], and the rate and frequency of injection (IPCC, 2013b; The Royal Society, 2009; Kravitz, 2013). Although most proposals have focused on the use of sulphate aerosols[59] – (hydrogen sulphide (H_2S) or sulphur dioxide (SO_2) – other potential options have been considered, including black carbon aerosols (Kravitz et al., 2012; Ban-Weiss and Caldeira, 2010) and special engineered particles (Keith, 2010; Teller E. et al., 1997; Benford and Benford, 2005).

Insights into the effectiveness and possible side effects of sulphate aerosol schemes have been mainly gained by numerical simulation models and/or natural analogues (Robock et al., 2008; Robock et al., 2012; Rasch et al., 2008; Ban-Weiss and Caldeira, 2010).

Recent studies indicate that injection of sulphate aerosol precursors of at least the amount of sulphur dioxide injected by the Mount Pinatubo eruption[60] would

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[58] Several methods of placing the aerosol precursors into the stratosphere have been proposed, including: airplanes, artillery shells, and stratospheric balloons Robock A, Marquardt A, Kravitz B, et al. (2009) Benefits, risks, and costs of stratospheric geoengineering. *Geophysical Research Letters* 36: L19703.

[59] This is mainly due to the well-studied analogue of large volcanic eruptions. Indeed, the natural cooling episodes produced in the past by volcanogenic sulphate aerosols, provide direct evidence that these particles would have the desirable cooling effect. The most significant eruption in recent times was Mount Pinatubo in the Philippines (12-16 June 1991), which reduced the GMST by ≈0.5 K within the year following the eruption The Royal Society. (2009) Geoengineering the climate: science, governance and uncertainty. London: The Royal Society, 98, Pope FD, Braesicke P, Grainger RG, et al. (2012) Stratospheric aerosol particles and solar-radiation management. *Nature Climate Change* advance online publication, Kravitz B. (2013) Stratospheric Aerosols for Solar Radiation Management. In: Lenton TM and Vaughan NE (eds) *Geoengineering Responses to Climate Change.* Springer New York, 21-38.

[60] Although Mount Pinatubo's eruption represents a stratospheric aerosol injection of the same order of magnitude as a full-scale deployment of a SRM scheme via sulphate aerosol injection, the analogy between the two cases is still imperfect Caldeira K, Bala G and Cao L. (2013) The science of geoengineering. *Annual Review of Earth and Planetary Sciences.* 231-256. As explained by Rasch et al. Rasch PJ, Tilmes S, Turco RP, et al. (2008) An overview of geoengineering of climate using stratospheric sulphate aerosols. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* 366: 4007-4037. "The aerosol forcing from an eruption lasts a few years at most, and eruptions occur only occasionally. There are many timescales within the Earth system, and their transient response to the eruption is not likely to be the same as the response to the continuous forcing required to

be needed annually to maintain a RF of -4 W m^{-2}, i.e. to offset the global-mean radiative forcing from a doubling of atmospheric CO_2 concentrations above preindustrial levels (Niemeier et al., 2011; Heckendorn et al., 2009; Pierce et al., 2010). However, a SRM strategy of this kind would likely affect the hydrological cycle (Trenberth and Dai, 2007)[61] and the atmospheric chemistry (Harris et al., 1997)[62]. Tilmes et al. (2008) showed that an injection of stratospheric sulphate aerosols of this scale would strongly increase the extent of Arctic ozone depletion and would cause a considerable delay (between 30 and 70 years) in the expected recovery of the Antarctic ozone hole (Tilmes et al., 2008). Robock et al. (2008) used a comprehensive atmosphere-ocean general circulation model (AOGCM) to further investigate the climate response to a SRM scheme via sulphate aerosol injection. The results of the modelling study suggest that "both tropical and Arctic SO_2 injection would disrupt the Asian and African summer monsoons, reducing precipitation to the food supply for billions of people". Finally, an abrupt termination of a sulphur aerosol injection scheme (or any other SRM approach) after 50 years of offsetting a 1 percent annum increase in CO_2 concentrations, would likely result in a rapid increase in global-mean temperature (with warming rates up to 4.1 times greater than the maximum rates under the business-as-usual CO2 scenario), accompanied by increases in global-mean precipitation (mean acceleration factor of 6.9) and decreases in sea-ice cover (Jones et al., 2013) [63].

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counter the warming associated with greenhouse gases. Furthermore, we have no precise information on the role the eruptions might have on a world warmer than today".

[61] Following the eruption of Mount Pinatubo there was a substantial decrease in precipitation over land and a record decrease in runoff and river discharge into the ocean. These results suggest that major adverse effects, including drought, could arise from the deployment of these SRM schemes.

[62] The authors suggested that the increase of halogen compounds following the eruption of Mount Pinatubo led to major ozone depletion in polar regions and to some extent in mid-latitudes.

[63] This is what has been termed the “Termination effect”, i.e. "the consequences of a sudden halt or failure of the geoengineering system. For SRM approaches, which aim to offset increases in greenhouse gases by reductions in absorbed solar radiation, failure could lead to a relatively rapid warming which would be more difficult to adapt to than the climate change that would have occurred in the absence of geoengineering. SRM methods that produce the largest negative changes, and which rely on advanced technology, are considered higher risks in this respect" UK House of Commons. Science and Technology Committee. (2010) The Regulation of Geoengineering. *Fifth Report of Session 2009–10.* London: The Stationery Office Limited: House of Commons. Science and Technology Committee, 116.

Despite these risks, injecting hydrogen sulphide (H_2S) or sulphur dioxide (SO_2) into the stratosphere is at present not prohibited or significantly restricted by the main international treaties governing the emission of those substances (Bodle, 2013).

- **3. Marine cloud-brightening** - Observations from clean marine air masses show that anthropogenic aerosols may enhance both cloud reflectivity and cloud cover, particularly for low-level marine clouds, which tend to cool the planet (Twomey, 1977). This has led some scientists to speculate about the possibility of increasing the number of droplets in - and hence the reflectivity of - marine stratocumulus clouds[64] to enhance the albedo of the Earth (Matthews and Keith, 2009).

  Accordingly, marine cloud brightening, also referred to as cloud albedo enhancement, cloud whitening or cloud seeding, describes a SRM technique by which clouds are increased and whitened over parts of the ocean to enhance clouds albedo, thus contributing to offset global warming by reflecting sunlight to space. The basic idea behind this technique is to enhance the reflectivity of low-level marine stratocumulus clouds by increasing the number of cloud condensation nuclei (CCN) (The Royal Society, 2009; Caldeira et al., 2013). Because present levels of anthropogenic pollution already provide a significant source of aerosols that affect cloud droplets, this SRM technique would be most effective in remote marine areas with a dust-free atmosphere (Vaughan and Lenton, 2011). Regions of persistent marine stratocumulus off the west coasts of Africa and North and South America, and other extensive regions of the southern oceans have been identified as regions where marine cloud brightening approaches would be effective (Latham et al., 2008). The successful implementation of cloud albedo enhancement strategy is dependent on other

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[64] Marine stratocumulus clouds exert a large influence on the radiation balance of the Earth due to their large aerial extent, temporal persistence, and high reflectivity of solar radiation King MD. (1993) Radiative Properties of Clouds. In: Hobbs PV (ed) *Aerosol-Cloud-Climate Interactions.* San Diego, CA: Academic Press, 123-149.

two key aspects: i) the creation of a supply of particles of an appropriate diameter and quantity to serve as CCN, and ii) the means used to deliver them (The Royal Society, 2009). Proposals aimed at addressing these issues have focused on the development of wind-driven spray vessels which would "sail back and forth perpendicular to the local prevailing wind and release micron-sized drops of seawater into the turbulent boundary layer beneath marine stratocumulus clouds" (Salter et al., 2008).

Recent model simulations indicate that up to 35% of the radiative forcing due to current levels of GHG could be offset by stratocumulus modification. This would delay the simulated global warming by about 25 years (Jones et al., 2009). However, if this SRM strategy were abruptly halted, the global mean temperature would return to a nongeoengineered value in around 5 – 10 years. This study concludes that while some areas of sub-Saharan Africa and Australia could benefit from large-scale cloud modification, with an increase in rainfall of 10-30 percent, the Amazonia and Nordeste regions of South America would experience decreases in precipitation, with reductions amounting to more that 50 percent in some places. This would affect the distribution of NPP, with reductions corresponding to 50-100 percent over a considerable area. The authors conclude that while some areas could benefit from this form of geoengineering, there are significant areas where the response could be very detrimental with implications for the practical applicability of such a scheme.

In another idealized scenario, where cloud droplets are reduced in size over all oceans uniformly to offset the temperature increase from a doubling of atmospheric $CO_{2,}$ the global-mean precipitation and evaporation decreases by about 1.3 percent, but the runoff over land increases by 7.5 percent (Bala et al., 2010). These different results in climate modelling of marine cloud brightening SRM have led the IPCC to conclude that "there is no consensus on its efficacy, in large part due to the high level of uncertainty about cloud radiative responses to aerosol changes" (IPCC, 2013b: 635).

- **4. Painting Roofs white** - Some authors have suggested that the albedo of urban regions can be increased by using highly reflective roofs and altering the material used in paving roads (Hamwey, 2007; Akbari et al., 2009; VanCuren, 2012; Oleson et al., 2010). A global albedo amplification effort may assume - at least in theory - that the total surface area of human settlements is capable of being 'whitened' (Jacobson and Ten Hoeve, 2011; Hamwey, 2007; Oleson et al., 2010).

  Akbari et al. (2009) suggested that urban albedo amplification technologies can raise roof albedos by about 0.25, and paved surface albedos by 0.15, resulting in a net albedo increase for urban areas of about 0.1. According to the authors, increasing the world-wide albedos of urban roofs and paved surfaces might induce a negative radiative forcing on the earth of -0.044 W m^{-2}, equivalent to offsetting about 44 Gt of CO_2 emissions.

  However, in addition to affecting albedo, conversion of rooftops worldwide to white roofs would change energy use, thus greenhouse gas and warming and cooling pollutant aerosol particle emissions (Jacobson and Ten Hoeve, 2011; Oleson et al., 2010).

  Oleson et al. (2010) examined the effects of globally installing white roofs using an urban canyon model coupled to a global climate model. This model also estimated large-scale space heating and air conditioning (HAC) fluxes by controlling internal building temperatures within specified comfort levels. The results indicated that global space heating increased more than air conditioning decreased. Nevertheless the annual mean heat island decreased by 33 percent over all urban areas. Although this model included feedbacks to the larger scale, the differences of temperatures were only estimated for urban areas and nearby areas (the globally-averaged temperature change due to white roofs was not estimated).

  To help bridge this gap, Jacobson and Hoeve (2011) estimated the climate response of theoretically converting all roofs within urban areas, taking into account both local heating and large-scale feedbacks. The results of this study suggest that "white roofs may reduce temperatures locally but may or may not reduce overall global warming worldwide". Indeed, the conversion of rooftops worldwide to white roofs, accounting for their albedo effect only, was calculated to cool population-weighted global temperatures by ≈0.02 K but to warm the Earth overall by ≈0.07 K.

- **5. Planting more reflective crops** - Geoengineering schemes to increase the albedo of vegetation have also been proposed as a potential strategy for helping counteract the warming caused by greenhouse gas emissions (Hamwey, 2007; Ridgwell et al., 2009; Doughty et al., 2011). The basic principle behind biogeoengineering or crop albedo geoengineering is to plant more reflective crops as a means to produce a net cooling effect on the planet. The effectiveness of vegetation albedo modification methods depends greatly on the albedo enhancement technique to be used and the area it would be applied to. There are several currently available possibilities for modifying the albedo of vegetation, including changes in choice of crop type, crop phenology and timing of practices. Additional strategies that could be developed in the future could include modifications of plant morphology such as modifying leaf characteristics to increase leaf pubescence, surface waxes, or canopy architecture to maximize albedo (Doughty et al., 2011).

  Recent proposals of crop albedo modification have been focused on grasslands, including open shrubland and savannah (Hamwey, 2007), and on croplands (Ridgwell et al., 2009; Doughty et al., 2011). The estimates for the potential increase in albedo vary greatly among these proposals.

  Hamwey (2007) suggested using either light-coloured shrubs, grass with variegated leaf colours or bioengineering grasses to increase by 25 percent the albedo of the world’s grasslands (7.5 percent of the Earth’s surface). Lenton and Vaughan (2009) estimated the radiative forcing of this proposal to be −0.51 W m^{-2} based on a surface albedo change of 0.003. Ridgwell et al. (2009) and Doughty et al. (2011) restricted their proposals to croplands and estimated albedo increases with ranges of 0.02–0.08 and 0.05–0.15, respectively.

Research on these SRM schemes is very much in its infancy and it is, therefore, difficult to assess these estimates and the feasibility of these proposals (The Royal Society, 2009; Vaughan and Lenton, 2011).

Potential side-effects, including i) reduced of overall primary productivity and crop yields; ii) reduced carbon uptake; iii) reduced evapotranspiration and precipitation; iv) loss of biodiversity; v) decreased food security; and vi) added sources of social conflict, also remain to be determined (Idem).

- **6. Covering desert surfaces with reflective material** - In theory, the albedo of deserts could also be enhanced to offset global warming. Hot deserts (including Sahara, Arabian, Australian deserts and Gobi) largely uninhabited, sparsely vegetated, and with a stable surface have been suggested as the most suitable areas for albedo modification (Gaskill, 2004). These areas cover about 2% of the Earth's surface area and have the highest insolation levels. Therefore SRM schemes aimed at enhance present albedo of the deserts (≈0.2 to 0.5) may have the potential to produce fairly large negative radiative forcings (The Royal Society, 2009).

  Gaskill (2004) suggested that an albedo increase from 0.36 to 0.8 over 4 million square miles of desert could be obtained with the addition of a reflective surface made of white plastic polyethylene film backed by aluminium foil[65]. The radiative forcing estimated for this project – The Global Albedo Enhancement Project (GAEP) – is -2.75 W m^{-2}. This estimate was later reduced to -1.45 W m^{-2} in improved calculations worked out by Lenton and Vaughan (2009).

  Using a series of AOGCM simulations Irvine et al. (2011) simulated the climatic effects of the GAEP project and concluded that global desert geoengineering, which is associated with significant global-scale changes in circulation and the hydrological cycle, would cause large regional-scale changes in precipitation with

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[65] The proposed desert modification material would require periodic replacement (every 3 years) and cleaning. It would be installed over a 60-year period and kept in place 150 years. An estimate of the cost of the GAEP, based on the maximum possible coverage of 4 million square miles done equally over 60 years, is $500 billion/year, or $75 trillion at the end of 150 years (Gaskill 2004).

a large reduction in the intensity of the Indian and African monsoons in particular.

With these examples in mind one can already get a sense of the scope and far-reaching ethical and social implications of geoengineering. This is clearly reflected by the way geoengineering has become a focus of theoretical speculation and controversy. In fact, the development of new geoengineering research initiatives, the rapid expansion of the scientific literature in the field and the growing number of policy reports over the past few years not only reveal the ever more plausible role that solar radiation management (SRM) and carbon dioxide removal (CDR) methods are likely to play in the portfolio of solutions to address climate change, but also reflect the growing concerns about the ethical and social issues that we need to address when considering the use of these technologies to avert the climate crisis.

3.3 Why is there a need to consider the social and ethical implications of geoengineering proposals?

> "*Any substantive advance in science or the introduction of a new technology is, in and of itself, a societal impact insofar as it has added to the body of knowledge or the technological capabilities of society in general. The depth and breadth of the impact may be small or large, but it is an impact nonetheless with moral and ethical implications. Impacts of any kind are rarely value neutra*l" (Bennett-Woods, 2008: 50).

As the previous section suggests, the different technological characteristics of geoengineering proposals, the different costs estimated for each method, the potential efficacy of their use, the levels of uncertainty associated with their deployment, and the distinctive risks they raise result in a multitude of solutions that seem difficult to bring together under the broad umbrella of the term geoengineering. For that reason some authors have been suggesting that the term "geoengineering" should be set aside, while also calling for the different CDR and SRM approaches to be analysed individually within a larger continuum of responses to climate change - Box 1.

"The term "geoengineering" is overbroad, unhelpful, and misleading, and should be set aside. I propose "climate management" or "CM" instead. (...) "Climate management" is less scary than "geoengineering," while still sinister enough to temper our enthusiasm; it is more accurate; and it fits within existing matrices of risk management and risk calculation" (Michaelson, 2010: 225; 229).

"Geoengineering is controversial—indeed, the term itself is controversial because it is both broad and imprecise. (...) We prefer the term “climate remediation,” which describes technologies that are intentionally designed to counteract the climate effects of past greenhouse gas emissions to the atmosphere" (Bipartisan Policy Center, 2011).

"Because of the longstanding ambiguity surrounding the term geoengineering, it is suggested that in the AR5, when assessing geoengineering options, the individual methods discussed might be referred to more specifically, i.e., by CDR and SRM rather than geoengineering, or when appropriate by the specific terms, e.g., cloud brightening, stratospheric aerosols, ocean fertilization, etc. (...) The risks and impacts of geoengineering techniques might be best assessed within the context of the risks and impacts of climate change and other responses to climate change such as mitigation and adaptation, rather than in isolation " (IPCC, 2012: 3-4).

"Concepts cease to be helpful when they are too broad, or too vague, and geoengineering is one such concept. Let future research and debate cease to be about “geoengineering” and instead focus on the specific features of proposed technologies, and the appropriate mix of emission reductions, CDR, SRM, adaptation, and rectification" (Heyward, 2013: 26).

Box 1 - Some attempts to redefine current proposals to intentionally engineer the Earth’s climate.

Contrary to these views, I stress the relevance and importance of keeping the term geoengineering on foot, otherwise losing the conceptual basis from which some important epistemological, ontological, and ethical questions can be raised. In fact, "disaggregating" the term in order to better focus on the specific risks, technological issues, economic aspects, or legal and regulatory frameworks that each geoengineering approach seems to imply must not come at the cost of bypassing the fundamental questions that these proposals encompass - and if not, the change in questions ought to be critically scrutinised.

Therefore, the significance of maintaining the term "geoengineering" extends beyond the need to take into account the three distinguished features that geoengineering proposals seem to encompass: global, intentional, and unnatural interventions (Schelling 1996). It also enables us to question the very essence of these proposals, inasmuch as all approaches to geoengineer the Earth's climate express an implied ontology (an embedded theory of who we are, how we are situated in the realm of being) and a presumed ethics (an embedded theory of how we ought to behave) (Weiskel, 2012). I thus share Hamilton's view that "the essence of geoengineering is nothing technological", and that beneath all emotional and ethical judgments lies an unexamined conception of the Earth (and of the human role in earthen nature) that makes geoengineering imaginable (Hamilton, 2013b: 3). It is precisely here that I see the need to consider the social and ethical implications of the "first technology of intentional planetary control" (*Idem, ibidem*). From this perspective I demarcate myself from the dominant features of the consequentialist worldview that have begun to ‘exhaust’ and ‘entrench’ the ethical debate on geoengineering into a ‘process of rational calculation’ – a process that has been largely informed by the ‘language of risk’[66] (Adam and Loon, 2000) and for which "the most ethical course is the best one determined by summing the value of the costs and benefits, perhaps weighted by risks, and maybe with some account of distributional effects" (Hamilton, 2011).

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[66] Whether by focusing on the risks of geoengineering technologies, or, in an almost paradoxical way, by assuming some of its specific methods as useful tools to manage climate risks

4. MAIN FINDINGS

In this chapter I will summarize and discuss the main findings of Papers I–VI in light of the research questions and point of departure presented in Chapter I. Therefore it comprises the following five sub-sections:

- Why is geoengineering becoming a part of the portfolio of response options to anthropogenic climate change?
- What ‘imaginaries’ of science and technology underlie geoengineering debates?
- How plausible are current geoengineering proposals?
- What are the expectations, the embedded values, and the ways of making sense of a geoengineered world?
- What kind of ethical framework can serve as a basis for assessing geoengineering proposals and inform policy responses to geoengineering governance?

4.1 Why is geoengineering becoming a part of the portfolio of response options to anthropogenic climate change?

The inertia of governments across the world to deliver tough action on climate change, the recent failures of the Doha round on trade agreements and the Copenhagen conference on climate change, the incapacity of short term national planning horizons to address long term climate change, the absence of effective policy levers to address the scale and complexity of the challenges involved in the transition to a low-carbon economy, the difficulty in realising the transformative requirements of social change that would come with effective climate change policy, and the prospect of a dramatic climate shift over the next century or two, are all factors that may help explain why we have arrived at the perilous juncture described in section 3.2, and why geoengineering has recently emerged as a topic of interest and discussion within the climate science community.

However, and as suggested in **PAPER IV,** to achieve a better understanding of why "geoengineering has been transformed from a topic discussed largely in science fiction and esoteric scientific papers into mainstream scientific and policy debate" (Macnaghten and Szerszynski, 2013: 465) it is necessary to critically examine the salient narratives that by capturing the shift in the relationship between humans and the global environment suggest the beginning of a potentially new geological epoch where human beings appear to have become a driving force in the evolution of the planet and geoengineering starts to look acceptable in preventing the worst effects of climate change.

Indeed, since the mid-1980s, when the Earth System Science Committee of the NASA Advisory Council put forward a more complete and unified approach to Earth studies a new way of understanding and studying the Earth system began to gain ground among scientific institutions around the world – Earth System Science (Earth System Sciences Committee, 1988; Earth System Sciences Committee, 1986). This new approach to Earth studies and global change, the recognition that humanity itself has become a global geophysical force, allied with new approaches and a growing commitment to achieving successful and effective planetary stewardship, are leading to a profound reorientation of the global environmental change research agenda, thereby opening up a wide range of new practices, techniques and mechanisms for global governance.

> "The advent of the Anthropocene, the time interval in which human activities now rival global geophysical processes, suggests that we need to fundamentally alter our relationship with the planet we inhabit. Many approaches could be adopted, ranging from geoengineering solutions that purposefully manipulate parts of the Earth System to becoming active stewards of our own life support system" (Steffen et al., 2011: 739).

It is against this background that the idea of geoengineering, as a potential new tool for addressing climate change, is gaining ground. In fact, each new step in the direction of an integrated Earth System Science seems to have reinforced the plausibility of geoengineering proposals within the wide range of options "towards good planetary management" (The Global Environmental Change Programmes, 2011). This is made clear by considering the impetus for geoengineering that came from novel structural concepts of Earth system science. Indeed, the intrinsically prescriptive nature of concepts such as ‘climate stabilisation’ and ‘Anthropocene’ seem to provide the ontological and epistemological underpinnings that brought geoengineering to the centre of the climate change debate.

4.2 What ‘imaginaries’ of science and technology underlie geoengineering debates?

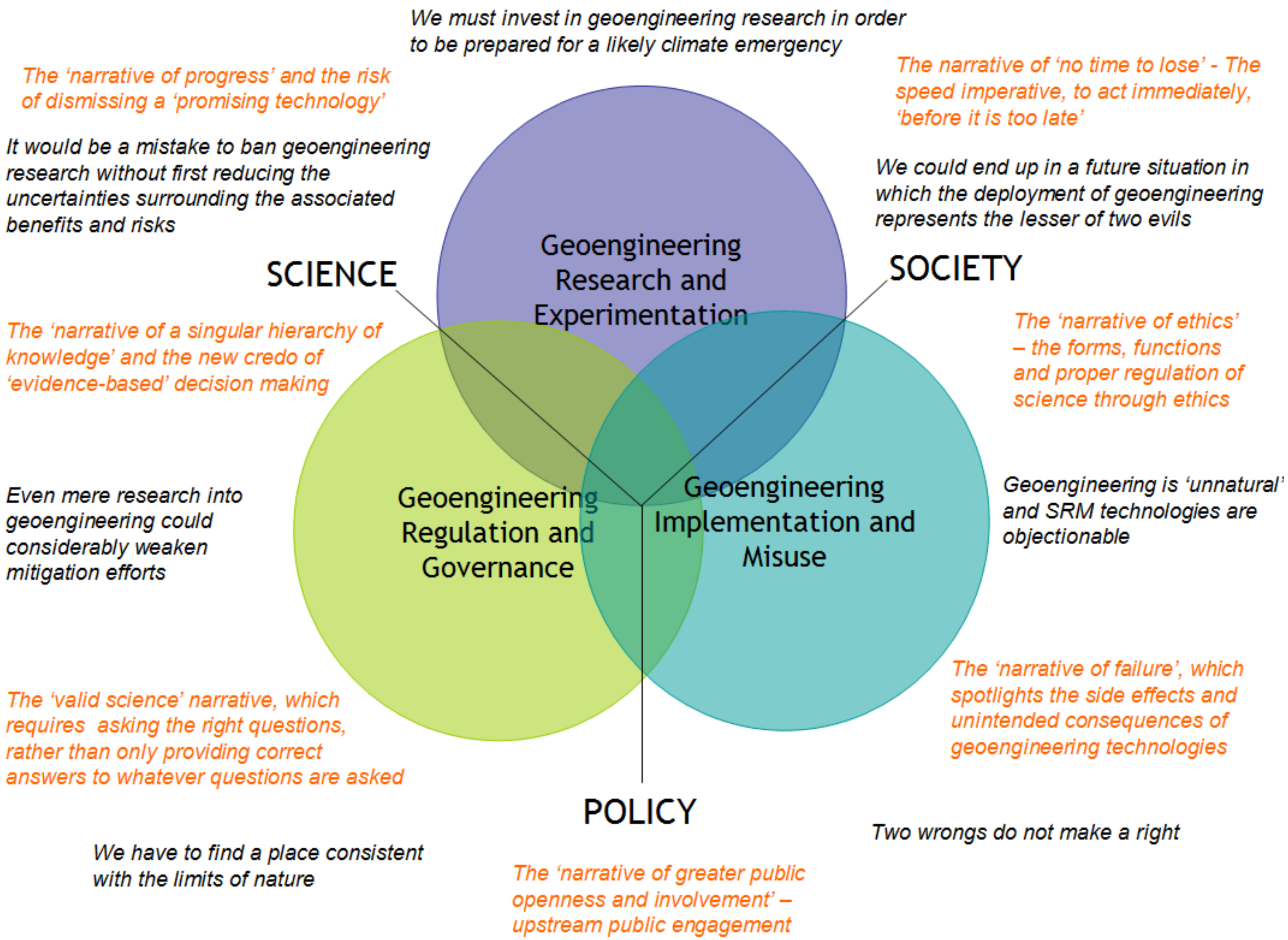
Different conceptions, understandings, and value assumptions concerning the changing relationships between science and society, science and technology, and science and nature tend to inform the geoengineering debate and sustain a variety of discursive frames that shape the way geoengineering has been problematised (Scholte et al., 2013; Sikka, 2012; Huttunen and Hildén, 2013; Luokkanen et al., 2013; Nerlich and Jaspal, 2012). Hence, the analysis of the geoengineering debate cannot be considered in isolation and apart from the context of its production; its full meaning can only be grasped in the context of the larger social imaginary of science and technology in which geoengineering narratives are rooted.

As the discussion of **PAPER VI** suggests, the Cartesian mechanistic worldview, with its emphasis on the instrumental mastery of nature, is deeply embedded in the dominant techno-scientific framing of climate change and in the range of practices that have produced the "coupled human and ecological system" as a "thinkable" and governable domain. This reinforces the need to unbind the geoengineering debate from the deeply embedded narratives of science, technology, and society which present technoscientific innovation as the solution to our most critical problems and as a substitute for social change. Similarly, the construction of narratives giving meaning to human action within nature, and providing guidance for humans’ domination of nature, deserves a more critical and open reflection than has been the case to date.

This was the focus of **PAPER I**, in which three interconnected areas of current debates on geoengineering were identified: geoengineering research and experimentation, geoengineering regulation and governance, and geoengineering implementation and misuse. Within these areas we have identified the main arguments called into question in the geoengineering debates and the underlying ‘master narratives’ in which they are embedded (Figure 9).

As suggested in **PAPER I**, the analysis of geoengineering debates may contribute not only to uncovering the variety of knowledge, values, and interests that compete in the climate change science, but also to mapping the dynamics of these debates in the context of the major narratives that are emerging in our society — thus seen as a valuable approach to understanding the mutual coproduction of science and society, in which "scientific knowledge both embeds and is embedded in social identities, institutions, representations and discourses" (Jasanoff, 2004b).

In this context, approaching geoengineering in a holistic manner is another way of looking at the problem of climate change and the ‘scalar dislocations’ it introduces in modern systems of experience and understanding (Jasanoff, 2010). In fact, the ethical, political, environmental, and social considerations that surround the debates on geoengineering tend to express political tensions and moral conflicts between experts, decision-makers, and the public, whether about the political control over the development of science and technology, whether about the values and principles underlying certain scientific practices and technological applications to pursue the common good. A reflection on these issues suggests the relevance of developing alternative approaches to furthering the ‘democratisation and de-alienation’ of geoengineering debates, thus responding to a perceived need for more careful consideration of the normative assumptions that lie behind the idea of deliberately manipulating Earth's climate to offset anthropogenic climate change.



We must invest in geoengineering research in order to be prepared for a likely climate emergency

The 'narrative of progress' and the risk of dismissing a 'promising technology'

It would be a mistake to ban geoengineering research without first reducing the uncertainties surrounding the associated benefits and risks

The 'narrative of a singular hierarchy of knowledge' and the new credo of 'evidence-based' decision making

Even mere research into geoengineering could considerably weaken mitigation efforts

The 'valid science' narrative, which requires asking the right questions, rather than only providing correct answers to whatever questions are asked

We have to find a place consistent with the limits of nature

The 'narrative of greater public openness and involvement' – upstream public engagement

Two wrongs do not make a right

The 'narrative of failure', which spotlights the side effects and unintended consequences of geoengineering technologies

Geoengineering is 'unnatural' and SRM technologies are objectionable

The 'narrative of ethics' – the forms, functions and proper regulation of science through ethics

We could end up in a future situation in which the deployment of geoengineering represents the lesser of two evils

The narrative of 'no time to lose' - The speed imperative, to act immediately, 'before it is too late'

Figure 9 - The three interconnected areas in which geoengineering debates are taking place: main arguments and underlying master narratives.

4.3 How plausible are current geoengineering proposals?

Why question the plausibility of geoengineering? Given the current state of affairs, in which geoengineering is receiving increasing consideration from academics and policy analysts as a possible means by which to offset human-induced climate change, this might seem a rather elementary or needless question. Yet, given the conflicting arguments and the variety of theses that inform the current debates on geoengineering, I was compelled to acknowledge that not only the need to address this question has to be taken more seriously, but also that answering it is inevitably far from straightforward.

> "The current debate on climate engineering is far more complex and multilayered than a purely scientific-economic analysis would indicate. To understand the complexity of the debate, it is necessary to collect, structure, and interrelate the wide range of arguments advanced in favor of or against climate engineering. (…) As the analysis reveals, individual arguments can frequently only be assessed for validity and plausibility when different disciplines are taken into account" (Rickels et al., 2011: 14).

Indeed, although plausible reasoning seems to play an important role in the ongoing debates on geoengineering, there is still a lack of understanding of how this "*practical epistemic device*" (Rescher, 2009) is being used within the context of the disputed arguments and controversial theses on the pros and cons of geoengineering research and deployment.

While some authors emphasise the plausible assumptions supporting the need for further and more in-depth research into the field of geoengineering — be it to increase our ability to access this topic, or ultimately, to deploy (in case of a climate emergency) the associated technologies — others draw attention to the highly inconsistent and implausible features that dominate the geoengineering debate (Table 1).

WHAT IS PLAUSIBLE IN GEOENGINEERING?	WHAT IS IMPLAUSIBLE IN GEOENGINEERING?
'(…) And as climate change impacts worsen with only tepid efforts to avoid it, geoengineering proponents can make increasingly plausible arguments that we may have little choice than to use geoengineering at least to some extent' (Wold et al., 2009: 119). *'Certainly, geoengineering seems to offer a*	*'The idea of geoengineering has a decades-long history, but it has until recently been relatively easy to dismiss it as implausible'* (Stilgoe, 2012: 201). *'It would be wrong simply to assume that all geoengineering projects are liable to the same problems. However, even if we do this and even if some geoengineering projects can meet the preceding fours*

WHAT IS PLAUSIBLE IN GEOENGINEERING?	WHAT IS IMPLAUSIBLE IN GEOENGINEERING?
plausible solution to the possibility of climate catastrophe in a way that attempting to reduce emission simply doesn't' (Morris, 2008: 145). *'Geoengineering appears to be a plausible means of "buying time" while humanity undergoes the profound changes in its use of energy and choices in transportation that are needed to eliminate GHG emissions'* (Hemming and Hagler, 2011: 274). *'It is plausible that, after exhausting other avenues to limit climate risks, such a nation might decide to begin a gradual, well monitored programme of SRM deployment, even without any international agreement on its regulation'* (Keith et al., 2010: 427). *'Given common estimates of the monetized cost of climate damages, the value of reducing climate change by geoengineering could exceed 1% of GDP. It is, therefore, plausible that the costs of geoengineering will be all but irrelevant to decisions about deployment, which will focus on the risk-to-risk trade-off between the risk of geoengineering and the risk of climate damages'* (Keith, 2010: 16430). *´If the objective of governance is to address risks and potential impacts of an activity, then activities involving the same risks and potential impacts should be treated the same regardless of whether an activity is carried out as "science" or as "deployment". On the other hand, some argue that following certain procedures and implementing safeguard is what constitutes research, and that therefore such activities should be treated differently. In contrast to the former view, this latter understanding appears to include plausible conditions for privileging geoengineering research to some extent'* (Bodle, 2013: 468). *'The moral hazard argument has been important in earlier debates about geoengineering and is plausible. It directly parallels arguments made in earlier years to oppose adaptation policy (Pielke et al. 2007). However there is little empirical evidence to support or refute the moral hazard argument in relation to geoengineering, (although there has been little research in this area), and it is possible that geoengineering actions could galvanise people into demanding more effective mitigation action'* (The Royal	*challenges, it would be highly implausible to think that a policy of geoengineering would entirely obviate the need for lowering greenhouse gas emissions'* (Caney, 2011: 83). *'Attempts to stave off ecocrisis through industrial-scale renewable energy, nuclear power and/or geo-engineering are deeply implausible if you admit the simple truth that "you can't grow your way out of a crisis if growth is what's causing the crisis in the first place'"* (Curry, 2011: 217). '(…) *there remains the problem of governing solar radiation management and of ensuring that the technology is deployed for good purposes – for example, to combat global warming rather than for national or regional advantage. Our participants regarded this prospect as highly implausible. Whether their judgement turns out to be justified, only time will tell, though it is quite possible'* (Macnaghten and Szerszynski, 2013: 472). '*Officially, climate policy is all about energy efficiency, renewables and nuclear power. Officially, the target of keeping global temperatures within two degrees of the pre-industrial revolution average is still in our sights. But the voices whispering that we might have left it too late are no longer automatically dismissed as heretical. Wouldn't it be better, they ask, to have at least considered some other options — in case things get really bad?* *This is the context in which various scary, implausible or simply bizarre* [geoengineering] *proposals are being put on the table'*. (Corner, 2013). *'It has been suggested that iron fertilization could represent an inexpensive carbon storage option; however, widely discussed cost estimates are questionable as they typically have been based on implausible assumptions including that exported carbon has high C/Fe ratios, that all of the added organic carbon exported from the euphotic zoneis balanced by a corresponding CO_2 influx from the atmosphere, and that CO_2 taken up by the ocean through iron fertilization remains there for a long time'* (Caldeira et al., 2004: 122-123). *'This claim that the moral permissibility of ocean fertilization cannot be adequately assessed independently of the actions that have necessitated it, we note, may seem* prima facie *implausible, as it seems to make dubious metaphysical suppositions. However, we should stress again that this is not a metaphysical position. Rather, the general idea is that the*

WHAT IS PLAUSIBLE IN GEOENGINEERING?	WHAT IS IMPLAUSIBLE IN GEOENGINEERING?
Society, 2009: 39).	*permissibility of an action is best established by appeal to and analysis of its most suitable description'* (Hale and Dilling, 2011: 205).
'It is also plausible that a major country, suddenly experiencing a serious local or regional climate disaster such as prolonged drought, could decide to do SRM unilaterally, thus imposing its consequences on the entire planet' (Morgan and Ricke, 2010: 16).	*'It has always struck me as implausible that any national leader would argue that geoengineering offers a safe alternative to emissions reductions — or that the American people would go along with the idea. Such a claim would require an extraordinary — indeed, I would say unobtainable — level of confidence in an unproven and manifestly imperfect technology'* (Thernstrom, 2010).
'I highlight the divergent results not to argue that one is more correct than other but to point out that in this case, two different research teams using very similar methods and just by varying assumptions about "deep uncertainties" arrived at results that are completely at odds with each other. *The conclusion, then, is that while it is certainly plausible that techniques of geoengineering could lead to very large benefits in relations to costs, it is also possible that those same techniques could lead to very large costs with respect to benefits'* (Roger Pielke Jr., 2010: 127).	*'But the dispersion of authority to different institutions will make it more difficult to consider geoengineering in an integrated manner. Suggestions to do so under the banner of the UNFCCC (for example, Lin 2009) are implausible, since the UNFCCC is seen as dysfunctional by many countries, and few trust its ability to make decisions'* (Bodansky, 2012).
'But what we know so far does suggest that, should the effects of climate change prove severe or even catastrophic—scenarios which are far from certain, but which appear increasingly plausible—geoengineering could be the only way of cooling the planet quickly, substantially, and sustainably' (Thernstrom, 2010).	*'Economic assessments are particularly open to instrumental framing effects relating to their treatment of sensitivities and the discounting of time. Whilst the BCA conducted by Bickel &Lane (2009) does include a number of different emission controls scenarios as well as market and ethical discount rates, these assumptions rely upon huge uncertainties in the literature. Furthermore in a demonstration of these methodological framings influencing outputs, another BCA using the same Dynamic Integrated model of Climate and the Economy (DICE) but different assumptions led to conflicting conclusions. Where stratospheric aerosol injection achieved an admirable benefit-cost ratio of 25 to 1 in Bickel & Lane (2009), Goes et al. (2011) concluded that the solar geoengineering proposal failed benefit-cost analysis under no less plausible assumptions (see Pielke Jr., 2010)'* (Bellamy et al., 2012: 18).
'I use a simple game theoretic model to demonstrate the following results. First, a credible threat that countries will deploy a geoengineering scheme can increase aggregate abatement to the level that the threat dissipates; the world reduces emissions to a level where geoengineering no longer makes sense. Second, the same credible threat can sustain a self-enforcing climate agreement with full participation and higher abatement than the non-cooperative scenario. I do not claim that these results are inevitable, but rather that they are just as plausible as a scenario under which geoengineering undermines abatement efforts' (Millard-Ball, 2012: 1048).	*'DAC [direct air capture] could at best be deployed slowly. Therefore, it is not at all matched to the task of reacting quickly to an abrupt climate emergency, for which the required rates of construction of facilities above and below ground are implausible'* (Socolow et al., 2011: i).
'Stratospheric aerosols are perhaps the most plausible solar geoengineering method thus far proposed, in part because they mimic a natural process that is known to cool the planet significantly – large volcanic eruptions which send sulphate aerosols high into the stratosphere for a period of about a year' (Low et al., 2013: 175).	*'All sorts of ideas have been proposed, from filling the stratosphere with reflective particles to giant space-borne parasols designed to shade the Earth from the sun. The idea of such a technological last chance, even if it sounds implausible, is a secret comfort to many of those frustrated by the lack of progress around the world in cutting emissions of greenhouse gases'* (MacCracken, 2009).

WHAT IS PLAUSIBLE IN GEOENGINEERING?	WHAT IS IMPLAUSIBLE IN GEOENGINEERING?
'Suppose, for example, that current political inertia on climate change is partly caused by a resistance to the kinds of norms of global justice and community that dealing with the problem might suggest. Then, it seems plausible that any geoengineering policy likely to emerge will be similarly constrained' (Gardiner, 2011a: 168).	*'There was similar scepticism about the possibility of ascertaining how much, of what, needs to be injected into the atmosphere to effectively and safely manage the climate system. For our participants, it was implausible to imagine that the effects of particulate injection could be known except in the context of full deployment, at a planetary level and across considerable timescales'* (Macnaghten and Szerszynski, 2013: 470).

Table 1 - The geoengineering debate: balancing the plausibility and implausibility of geoengineering proposals.

A close reading of these quotations illustrates how the concept of plausibility has been invoked in a variety of contexts, such as those related with: i) the description, or formulation, of the conditions that justify acknowledging the arguments in favour of research into and possible deployment of geoengineering; ii) the attempts to bring into prominence the epistemic and nonepistemic values attached to geoengineering proposals; iii) the disentanglement of the kinds of world that geoengineering might bring into being; iv) the critical exploration of the assumptions that underpin governance debates around these technologies; and finally v) the discussion about the underlying assumptions of technical and economical assessments conducted in this field.

As discussed in **PAPER V**, in the field of geoengineering, where knowledge is incomplete, uncertain, and inconsistent, the inductive and deductive arguments that one would expect to encounter in the scientific model of justification — the positivistic model of scientific verification of empirical and analytic propositions — seem to intermingle with a third class of arguments, the so-called abductive, presumptive, or plausibilistic forms of argumentation (Walton, 2003). This class of arguments is based on a kind of plausible reasoning that combines normative or value-stating premises (premises stating general rules) with premises drawn from the presumed facts of a case — be it a simulation model that seeks to address the climatic consequences of geoengineering proposals (Matthews and Caldeira, 2007; Lenton and Vaughan, 2009), a limited and controlled real-world geoengineering experiment (Pidgeon et al., 2013), or an assessment of different geoengineering techniques in terms of efficiency, affordability, safety, controllability, timeliness, or reversibility (The Royal Society, 2009; Vaughan and Lenton, 2011; Boyd, 2008).

Indeed, the contexts in which the concept of plausibility has been used and the set of things it refers to[67] not only reveal “a very large class of plausibility reckonings deeply embedded in actual cognitive practice” (Gabbay and Woods, 2005a: 237), but also expose the dual nature of plausibility in hypothetical reasoning:

> "Plausibility trisects reasoning in characteristic ways. We can conceive of the plausible **as that which is reasoned from** and **as that which is reasoned to**. We can also see it as characterizing the inference link between **what is reasoned from** and **what is reasoned to**. Seen this way, a piece of reasoning may have premisses that are plausible; it may have a plausible proposition as its conclusion; and its conclusion may be plausibly inferred from its premisses. It is also notable that plausibility is ambiguous as between propositions and what we might call the “engagement of propositions”. The two are logically independent. Planck famously thought that his quantum hypothesis was radically implausible, but he conjectured it all the same, illustrating that it can sometimes be reasonable to accept (if only tentatively) the unreasonable. Given the linguistic tie between the reasonable and the plausible, a like concurrence affects the plausible. **Accordingly we shall distinguish propositional plausibility from strategic plausibility"** (Gabbay and Woods, 2005b: 68, emphasis added).

This distinction points to the ambiguous cognitive and epistemic status of plausibility and highlights the importance of considering both the explanatory and instrumental aspects of abductive reasoning (Magnani, 2009) in the context of the geoengineering debate, where the two different kinds of plausible contentions (propositional and strategic plausibility) are being brought into play to answer two very different kinds of questions: **What is it reasonable to believe?** and **What is it reasonable to do?**

According to Hodgson, these two questions involve the type of decisions that "cannot be made by overt calculation or computation or any other way involving the overt mechanical application of conclusive rules" (Hodgson, 2012: 39). As he argues, these are rather the typical questions that can only be answered by the exercise of reasonable

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[67] Of which the following are just a few examples: the plausible, or implausible, ideas of controlling the global climate; the plausible, or implausible, conjectures about future institutional arrangements and the appropriate policy mechanisms to address the geoengineering governance challenges; the plausible, or implausible, assumptions about deep uncertainties underlying economic assessments in the field; the plausible, or implausible, social and ethical implications regarding the use of certain geoengineering methods, etc.

(albeit fallible) judgment. In fact, the need to engage in this kind of (inconclusive) plausible reasoning cannot be eliminated by the ability to use the logical structure of scientific knowledge – or what Walter Fisher refers to as the “logic of reasons” associated with the “rational world paradigm” (Fisher, 1987). In this sort of situation – when we are confronted with these kinds of questions, when we need to make judgments on the basis of inconclusive reasons, when we need to “transform the logic of reasons into a logic of good reasons” – the “narrative paradigm” offers a means of transcending the “uncompromising and irreducible oppositions presented by all kinds of absolutisms: dualisms of reason and imagination, of knowledge and opinion, of irrefutable self-evidence and deceptive will, of a universally accepted objectivity and an uncommunicable subjectivity, of a reality binding on everybody and values that are purely individual” (Perelman and Olbrechts-Tyteca, 1969: 510).

This goes some way toward recapturing “the Aristotelian question of balancing instrumental rationality with value-rationality” (Flyvbjerg, 2001: 53; Flyvbjerg, 2004). Accordingly, when analysing the various qualities of plausible claims deemed important in the field of geoengineering, I stressed the relevance of considering the neo-Aristotelian accounts of practical reasoning that, rooted in a critique of modern instrumental technical rationality, seek to redress the imbalance between the intellectual virtues of *episteme*, *techne* and *phronesis*[68] (Flyvbjerg, 2001).

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[68] The intellectual virtue that Aristotle calls *episteme* concerns universals and the production of knowledge that is invariable and context-independent. It corresponds to the modern scientific ideal as expressed in natural sciences, being generally translated as “science” or “scientific knowledge”. *Techne* can be translated into English as “art” in the sense of “craft”. Its objective concerns the applications of technical knowledge and skills according to a pragmatic instrumental rationality. It is therefore an activity that is variable and context-dependent. Whereas *episteme* concerns theoretical *know why*, *techne* denotes technical *know how. Phronesis* concerns values, and goes beyond analytic rationality (*episteme*) and technical knowledge (*techne*). It involves judgements and decisions made in the manner of a virtuoso social actor; the ability “*to deliberate nobly about things good and advantageous for himself, not in a partial way—for example, the sorts of things conducive to health or to strength—but about the sorts of things conducive to living well in general*” Bartlett RC and Collins SD. (2011) *Aristotle’s Nicomachean Ethics. Translated, with Interpretive Essay, Notes, and Glossary,* Chicago: University of Chicago Press. Thereby, it is often translated as “prudence”, “practical common sense” or “practical wisdom” Flyvbjerg B. (2001) *Making Social Science Matter. Why social inquiry fails and how it can succeed again,* Cambridge, UK: Cambridge University Press, Flyvbjerg B. (2004) Phronetic Planning Research: Theoretical and Methodological Reflections. *Planning Theory & Practice* 4: 283-306. For further discussion, see: Eikeland O. (2008) *The Ways of Aristotle. Aristotelian phrónêsis, Aristotelian Philosophy of Dialogue, and Action*

With this background in mind, I now return to the quotations in Table 1 to suggest that the considerations of reasonability and plausibility that lie at the heart of the geoengineering debate should be understood as manifestations of a reasoning process in-between two theoretical traditions, namely: i) the instrumental technical rationality of modern conceptions of scientific reasoning (the epistemological stance engendered by enlightenment rationality and logical positivism) and ii) the tradition of practical reasoning that draws on practical value-rationality to challenge the logical empiricism, its ontological privileging of scientific knowledge, and the adequacy of "instrumental rationality alone".

These kinds of considerations are also embedded in the pictorial narratives of geoengineering, with their implied reasoning corresponding in many ways to a form of narrative rationality pertaining to rhetorical action - **PAPER V**. As the four images included in this paper suggest, plausibility not only plays a central role in the discovery, pursuit, and justification of geoengineering hypotheses, but also constitutes the fundamental practical epistemic device for seeking the answers to the two above-mentioned questions: *What is it reasonable to believe?* and *What is it reasonable to do?*

4.4 What are the expectations, the embedded values, and the ways of making sense of a geoengineered world?

In **PAPER II** and **PAPER V** I focused on the entanglement of imaging and imagining – "imag(in)ing" [69]– with a view to exploring the potential of a visual narrative approach for

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Research, Bern: Peter Lang AG, MacIntyre A. (1984) *After Virtue: A Study in Moral Theory,* Notre Dame: Notre Dame University Press.

[69] The word "imag(in)ing" aims at capturing the continuum between imaging and imagining, referring to something that has not only to do with the way an image may bear some resemblance to that which it represents, but also with the way it might "stand for'" and is able to "act for" (Ruivenkamp and Rip 2011, p.185). It thus refers to the realm of symbolic action, in the sense that visual representations "have sequence and meaning for those who live, create, or interpret them" (Fisher 1987, 1985) and might provide a meaning and a rationale for decision and action.

better understanding the expectations, the embedded values, and the ways of making sense of a geoengineered world.

As I hope to have been able to demonstrate, the visual representations of geoengineering offer a privileged perspective from which to address this question. In fact, the images that populate the world of geoengineering tend to balance the past, present, and future in order to communicate the results of recent experiments, as well as to present the potentialities, drawbacks, and risks associated with its associated technologies. By combining present achievements in this field with visions of what it may become, the visual representations of geoengineering draw attention to the anachronism that tends to be associated with innovation processes in the context of knowledge production. These are entanglements of the present and the future, of the world in which we live and of worlds that might be realised; of a science that has to deal with our incomplete, inconsistent, and uncertain knowledge and a science that aspires to precision and exactitude; of a humanity constrained by its very nature and a humanity that aspires to transcend its own nature.

This last aspect is clearly illustrated in an article, published in *Tikkun magazine*, by Paul Wapner about the “moral character of two environmentalisms”, namely: the traditional environmentalism, which strives for naturalism, and the new environmentalism, which strives for mastery.

> "Traditional environmentalism taught us to live humbly within nature’s limits. A new environmentalism, which assumes we can’t learn fast enough to live humbly, embraces geo-engineering ideas as our main hope for cooling the planet" (Wapner, 2010).

According to Wapner, the new environmentalists are “now admitting that global capitalism, incessant technological innovation, endless consumption, and pervasive anthropocentrism are here to stay. So, rather than continue to battle against these dynamics in the service of living more harmoniously with the natural world, many argue that it is time to embrace them and align ourselves with their power” (idem). Figure 10 shows the image included in this article to illustrate the inconsistencies of a new environmentalism that ignores naturalism – an image that has the power to confront us with the implausible story that portrays the “little prince” as a “little geo-engineer”.

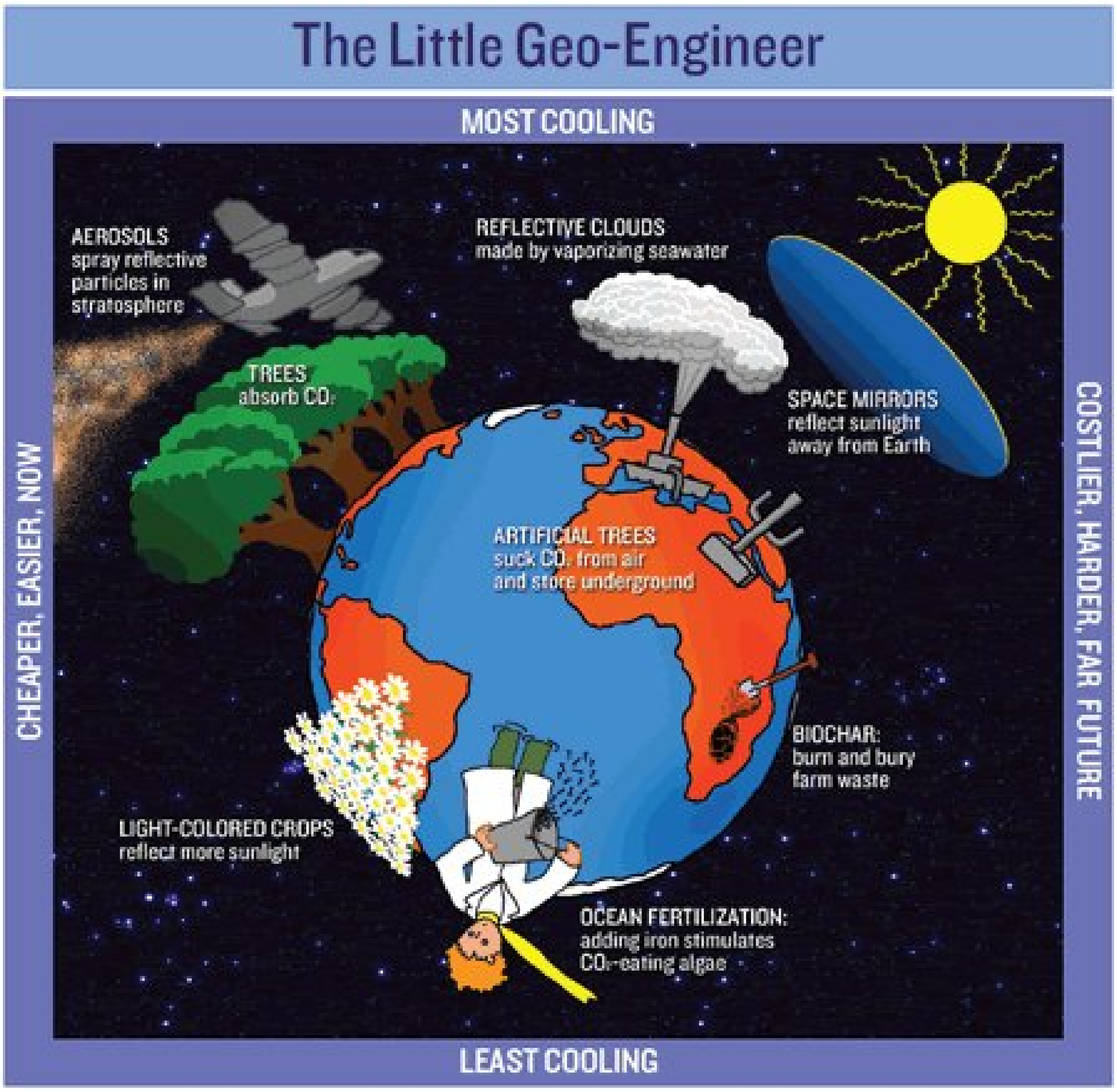

Figure 10 - The Little Geo- engineer. Source: Wapner, P. (2010)

It seems a contradiction, but the idea is clear, the little prince lives in a universe populated with planets dominated by those he has met throughout the story (the king, the vain man, the businessman, the lamplighter, the geographer) — those that in the book were concerned with “matters of consequence”. But if the narrator of the book says that “the little prince's ideas about what was important were very different from those of grown-ups” (Saint-Exupéry, 1995: 56), it seems here that he has given up those ideas. The concerns of the little prince have shifted from essential matters and his personal affairs — the quiet pleasure of looking at the sunset, his dedication to “cleaning out his volcanoes” and “to attend the toilet of his planet with the greatest care” — to “matters of consequence” that is: brightening the clouds, fertilising the ocean with iron, pumping aerosols into the upper atmosphere, and so forth.

And it is precisely this new little prince, the little geo-engineer who personifies the “New Environmentalism”, the one who says that “the problem is not that we are doing too much — pumping too much carbon into the atmosphere — but that we’re doing too little - we are not working hard enough to alter the atmosphere*”* (Wapner, 2011: 184). This might seem an implausible perspective and a twisted way of looking at the climate change problem. However, some more elaborated, and seemingly plausible, versions of this perspective are not difficult to find:

> "We have been actively engaged in a massive programme of global geoengineering for many decades or centuries. We need to recognize this activity and change the way we think about the earth - not just our impact on the planet, but how (or if) we should manage the situation. (...) Once we recognize our environmental imperative to carefully and thoughtfully manage our planet for maintaining the health of all component earth systems and tackle the ethical issues of geoengineering, we can move away from accidental or poorly planned geoengineering into an era of conscious geodesign*"* (Artz and Dangermond, 2011: 4-5).

By revealing the contradictions of a new environmentalism that ignores naturalism, the implausible story that portrays the little prince as a little geo-engineer confronts us with a situation of aporetic inconsistency, that is a situation where a group of contentions seem individually plausible but are collectively incompatible (Rescher, 2009).

The root idea of aporetics — the theory of rational deliberation in the face of inconsistencies — “lies in the combination of reductive control in situations where we have succumbed to the cognitive overcommitment of inconsistency and find ourselves having to salvage some part of what must be abandoned” (Rescher, 2009: ix). According to Rescher, the tendency to hypertrophy that arises from the conjunction of conflicting propositions can only be countered by a plausibility analysis, a process that enables the “chain of inconsistency” to be broken by abandoning one or more of the contentions (the weakest links) that cannot be maintained together. Because this process of analysis encompasses a variety of cognitive endeavours, Rescher proposes a method to synthesise and systemise an aporetic procedure — coherence tropism via plausibility analysis — that can be used whenever we are confronted with threatening situations of cognitive dissonance and/or inconsistency. In this context, “plausibility-tropism” can be seen as an instrument of epistemic prudence, closely analogous to the prudential principle of action — that is, opting for the available alternative from which the least possible harm can result (Rescher, 2003: 87). Accordingly, a possible prudential means for coming to terms with the inconsistencies that prevail in the geoengineering debate is through rational management of its apories. Here is another example of a fundamental apory in geoengineering that can only be resolved by simply abandoning some (or all) of the commitments whose conjoining creates a contradiction:

> "A serious effort on geoengineering looks like a wonderfully secure employment program for climate scientists, yet many climate scientists are very worried about geoengineering. Some pundits and other people express doubts about the quality of climate science and our understanding of global warming, while expressing confidence that we can easily and safely geoengineer our way out of global warming if it becomes a big problem. However, these two ideas are highly inconsistent — confidence in geoengineering requires confident climate science" (Alley, 2011: p. 311).

Although the resolution of this apory does not seem a very difficult task, there is still a resistance to consider the far-reaching implications of its result.

4.5 What kind of ethical framework can serve as a basis for assessing geoengineering proposals and inform policy responses to geoengineering governance?

In **PAPER III** and **PAPER IV** two different contextual frameworks from which to address the ethical issues in geoengineering were presented and analysed. The first represents the mainstream Earth system science perspective, while the second one corresponds to an alternative view from the field of social studies of science and technology. Central to both is the concept of an ‘epochal break’, in the former in terms of the Human-Earth relationship, in the latter in terms of the relationship between science, technology and society.

By stressing the relevance of considering the close links between thought and intervention, in **PAPER IV** I drew upon the analytical concept of Earth system governmentality (Lövbrand et al., 2009) to suggest that the large continuum of possible government programmes for sustainability should constitute the backbone of the analytical framework to address the ethical issues of geoengineering. Indeed, the analysis of geoengineering within this continuum may provide valuable insights for addressing what have been tentatively agreed as the five main properties of "ethically sound frameworks", namely:

- <u>Inclusion of values at stake</u> – making explicit the values at stake in any decision;
- <u>Transparency</u> – overcoming the 'opaqueness' of moral decision-making;
- <u>Multiplicity of viewpoints</u> – taking into account the multiplicity/plurality of known ethical viewpoints;
- <u>Exposition of case-relevant ethically relevant aspects</u> – taking into consideration all ethically relevant aspects of the issue, including the factual information that potentially contributes to strengthening or weakening a particular outcome or judgment;
- <u>Inclusion of ethical arguments</u> – understanding the arguments behind a particular decision, in order to enable rational critique and debate.

The fundamental assumptions underlying the design of the proposed framework were as follows: i) the need to be sufficiently comprehensive in order to capture the different perspectives on geoengineering and allow access to all relevant facts and normative considerations that lie behind a particular position; ii) the need to identify the salient ethical concerns according to which the social and ethical impacts of geoengineering can be assessed; iii) the possibility of subjecting the conflicting moral accounts to rigorous examination in the light of agreed ethical principles; and, last but not least, iv) the need to provide substance for ethical deliberation, so as to help decision-makers reach sound judgments and responsible decisions about the ethical acceptability of geoengineering research and deployment.

Thus, building upon previous efforts to identify an appropriate tool for rational ethical analysis, I adopted (with the necessary adaptations) the approach developed by Prof. Ben Mepham and his colleagues at the University of Nottingham in the early 1990s for translating some of the criteria of "ethically sound frameworks" into a procedural and substantive tool [70] – the Ethical Matrix (Kaiser et al., 2007; Mepham, 2000; Mepham, 2005; Mepham, 1996; Mepham et al., 2006; Mepham et al., 1996).

In line with the approach developed by Beauchamp and Childress in the field of biomedical ethics, the ethical matrix (EM) uses a "principled" approach to ethics, appealing to a set of *prima facie* principles (i.e. rules of action that are "valid at first appearance"). Hence, the three basic principles employed in the EM were chosen to represent the major traditional ethical theories, namely: i) respect for wellbeing, representing the major utilitarian principle; ii) respect for autonomy, representing the major deontological principle; and iii) fairness, representing respect for justice (Rawls, 1951; Rawls, 1972), which is derived from both utilitarian and deontological theories (Mepham, 2005). These three *prima facie* principles together represent what is referred to as common morality, i.e. "moral norms that bind all persons in all places" (Beauchamp and Childress, 2001: 3), and their inclusion in the framework acknowledges the plurality of perspectives that might be brought to an ethical analysis (Mepham, 2010). As we can see in Table 2, this ethical component of the method forms the columns of the EM.

The second component of the method, listed in rows, consists of a set of selected interest groups or parties affected by the issue in question. In the case of geoengineering, the list of potentially affected interest groups is broad (including most nations, subnational groups, nongovernmental organisations, corporations and civil

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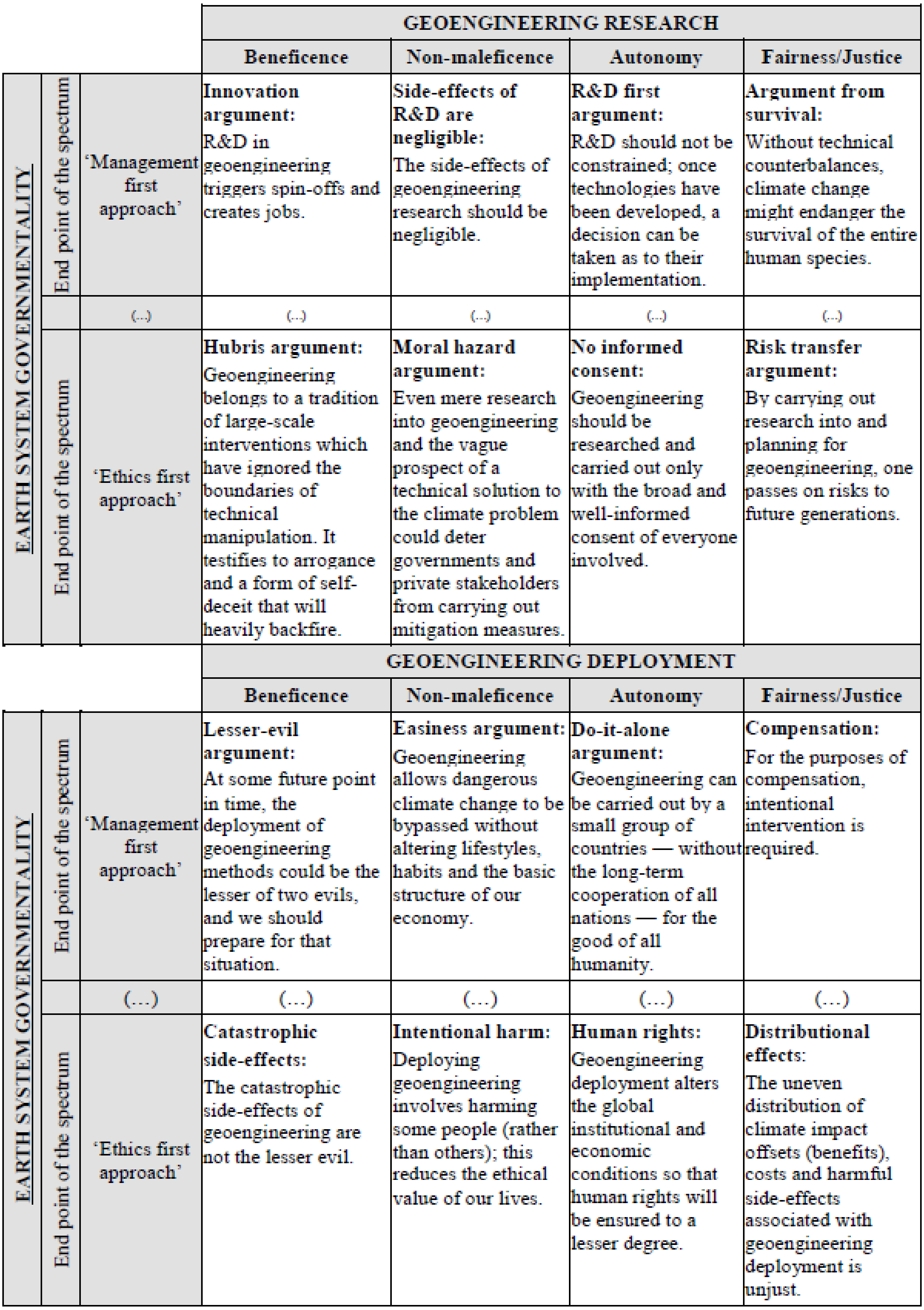
[70] "By bringing ethical considerations to the fore, it acts as a substantive ethical tool; and by requiring policy-makers to articulate their assessments of impacts on each cell of the matrix, it acts as a procedural tool" Mepham B. (2010) The Ethical Matrix as a Tool in Policy Interventions: The Obesity Crisis. In: Franz-Theo Gottwald, Ingensiep HW and Meinhardt M (eds) *Food Ethics.* Dordrecht: Springer, 17-30.



			GEOENGINEERING RESEARCH			
			Beneficence	**Non-maleficence**	**Autonomy**	**Fairness/Justice**
EARTH SYSTEM GOVERNMENTALITY	End point of the spectrum	‘Management first approach’	**Innovation argument:** R&D in geoengineering triggers spin-offs and creates jobs.	**Side-effects of R&D are negligible:** The side-effects of geoengineering research should be negligible.	**R&D first argument:** R&D should not be constrained; once technologies have been developed, a decision can be taken as to their implementation.	**Argument from survival:** Without technical counterbalances, climate change might endanger the survival of the entire human species.
		(...)	(...)	(...)	(...)	(...)
	End point of the spectrum	‘Ethics first approach’	**Hubris argument:** Geoengineering belongs to a tradition of large-scale interventions which have ignored the boundaries of technical manipulation. It testifies to arrogance and a form of self-deceit that will heavily backfire.	**Moral hazard argument:** Even mere research into geoengineering and the vague prospect of a technical solution to the climate problem could deter governments and private stakeholders from carrying out mitigation measures.	**No informed consent:** Geoengineering should be researched and carried out only with the broad and well-informed consent of everyone involved.	**Risk transfer argument:** By carrying out research into and planning for geoengineering, one passes on risks to future generations.
			GEOENGINEERING DEPLOYMENT			
			Beneficence	**Non-maleficence**	**Autonomy**	**Fairness/Justice**
EARTH SYSTEM GOVERNMENTALITY	End point of the spectrum	‘Management first approach’	**Lesser-evil argument:** At some future point in time, the deployment of geoengineering methods could be the lesser of two evils, and we should prepare for that situation.	**Easiness argument:** Geoengineering allows dangerous climate change to be bypassed without altering lifestyles, habits and the basic structure of our economy.	**Do-it-alone argument:** Geoengineering can be carried out by a small group of countries — without the long-term cooperation of all nations — for the good of all humanity.	**Compensation:** For the purposes of compensation, intentional intervention is required.
		(…)	(…)	(…)	(…)	(…)
	End point of the spectrum	‘Ethics first approach’	**Catastrophic side-effects:** The catastrophic side-effects of geoengineering are not the lesser evil.	**Intentional harm:** Deploying geoengineering involves harming some people (rather than others); this reduces the ethical value of our lives.	**Human rights:** Geoengineering deployment alters the global institutional and economic conditions so that human rights will be ensured to a lesser degree.	**Distributional effects:** The uneven distribution of climate impact offsets (benefits), costs and harmful side-effects associated with geoengineering deployment is unjust.

Table 2 - The ethical matrix revisited: towards an analytical framework for evaluating the ethical dimensions of geoengineering research and deployment.

societies). Thus, and because "the global impacts of geoengineering activities – both its benefits and risks – may be unevenly distributed across stakeholders" (Bracmort et al., 2011: 21), I suggested that the best way to capture the explicit listing of stakeholders' viewpoints is to consider the large spectrum of possible government programmes for sustainability that the concept of Earth system governmentality encompasses. Accordingly, the first and last rows of Table 2 depict the extremes of this continuum, i.e. the two types of government programme for sustainability ('management first' and 'ethics first') that occupy the end-points of the Anthropocene imagery (Lovbrand et al., 2009).

The 'management first' approach "draws upon the optimistic view of human control and self-determination embedded in Earth System thinking and focuses on options and caveats for technological fixes and geoengineering" (Idem). The first row of the EM (structured around established ethical theories) sets out the main arguments that have been advanced under this approach in the geoengineering debate, which, together, tend to sustain the idea that *we need to go further and faster in researching and deploying these technologies*.

The counterpoint of this extreme interpretation of the Anthropocene is set out in the last row of the EM, which represents the 'ethics first' approach – "*humbled by the scale, complexity and vulnerability of the Earth System, this political programme highlights the need for a new ethical framework for Earth stewardship*" (Idem). Accordingly, this lists the main arguments that have been advanced against geoengineering research and deployment - direct justification of a research ban and an international moratorium on deployment (Rickels et al., 2011).

The outline of this framework underlines the importance of facilitating deliberative assessments in order to map the plurality of perspectives and explore qualitative aspects of uncertainty in and around geoengineering. Thus, the empty spaces between these two extreme end-points of the Anthropocene imagery reflect the scope for democratic decision-making and public engagement in the field of geoengineering.

5. CONCLUSION AND FURTHER DEVELOPMENTS

> "*(...) with certain developments of our powers the nature of human action has changed, and, since ethics is concerned with action, it should follow that the changed nature of human action calls for a change in ethics as well: this not merely in the sense that new objects of action have added to the case material on which received rules of conduct are to be applied, but in the more radical sense that the qualitatively novel nature of certain of our actions has opened up a whole new dimension of ethical relevance for which there is no precedent in the standards and canons of traditional ethics*" (Jonas, 1984: ix).

5.1 Conclusion

Questions concerning how human beings ought to behave with regard to the natural world can hardly be said to be new. Prescriptions concerning human attitudes and behaviour toward the natural world have existed throughout human history (Palmer, 2003). By translating our values, these prescriptions are typically connected to both our moral standards and our beliefs (Kaiser, 1997).

As the results of this study suggest, a particular conception of the world and of our place in it needs to be questioned if the ethical and social issues of geoengineering are to be taken seriously. The point here is not simply to question the risks that geoengineering proposals may bring as a response to the escalating climate change problem, but rather to question the "axiomatic beliefs" that underpin these proposals. As Kaiser pointed out (1997: 329), the more fundamental beliefs about both nature and society are largely unaffected by science, assuming a more axiomatic status and forming part of the "myths of nature" that lie at the roots of our behaviour and ethics.

The myths of nature are a typology that captures different interpretations of ecosystem stability, translating how agencies managing ecosystems have adopted different strategies in the face of similar environmental problems (Holling, 1979; Timmerman, 1986; Holling, 1986). The four myths of nature - nature capricious, nature benign, nature ephemeral, and nature perverse/tolerant - can be graphically represented by adopting the metaphor of a sphere rolling in a landscape (Schwarz and Thompson, 1990), where the rolling ball represents the state of nature and the line/curve represents the system's behaviour (Figure 11). The position of the ball indicated in Figure 11 represents the state where human beings live in harmony with nature (Hofstetter, 1998).

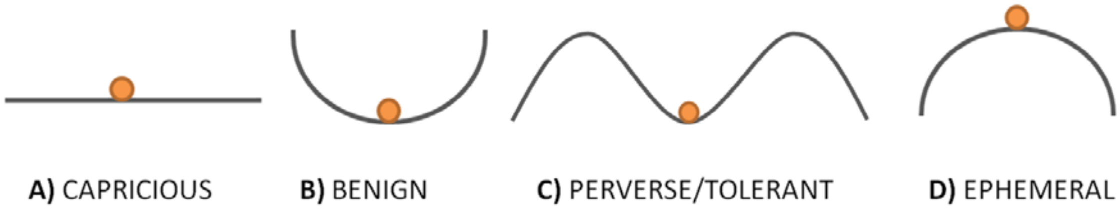
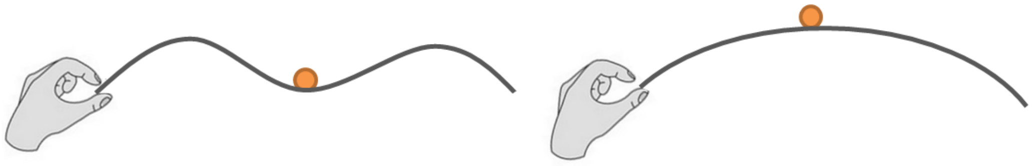


Figure 11 - Depiction of four myths of nature (derived from Thompson et al. 1990, p. 5).

Each of these myths are the result of different beliefs of how nature functions, which in turn is closely related with the fundamental beliefs about the ways human beings can act upon the natural world in which they live. The most static view is that of "nature capricious" or "nature flat" (Holling et al., 2002). This myth describes a random world in which there are few or no forces affecting stability. In such a view of nature there are no consequences of human actions and, therefore, policies and politics are random. The second myth, "nature benign" refers to the equilibrium-centred view. "Such a world is wonderfully forgiving: no matter what knocks we deliver the ball will always return to the bottom of the basin" (Schwarz and Thompson, 1990: 5). The third view, "nature perverse/tolerant", assumes that multiple equilibrium states are possible, or even necessary. The word is robust within certain limits and is forgiving of most events. However, crossing some thresholds may produce changes that are either irreversible or extremely difficult to reverse. The agencies managing ecosystems must therefore regulate against the risk of crossing thresholds that will trigger non-linear and abrupt environmental changes. Finally, "nature ephemeral", or the "myth of instability", is one where the system is globally unstable. In this view the world is a "terribly unforgiving place", where the least jolt may cause its complete collapse (Schwarz and Thompson, 1990). "It is a view dominated by hyperbolic processes of growth and collapse, where increase is inevitably followed by decrease" (Holling et al., 2002: 13), and where managing institutions must treat the ecosystem with great care in order to prevent a catastrophic collapse.

As I hope to have shown throughout this study, geoengineering combines the narratives of risk, inevitability and stewardship of the two last myths of nature with ideals of mastery and control to suggest that it is indeed possible to alter the way nature works. The perversity of nature, or its ephemerality, can definitely be changed by geoengineering - we no longer have to wait for its forgiveness (Figure 12).



C1) PERVERSE/TOLERANT ONLY IF ...

D1) EPHEMERAL ONLY IF...

Figure 12 - The myths of nature (and of the human being) that underpin the idea of a geoengineered world.

Although these ideals of mastery and control have their roots in the Enlightenment and in the Cartesian mechanistic worldview that marked the modern scientific project (**PAPER VI**), geoengineering seems nonetheless to entail a particular way of thinking about the world, leading to different assumptions about stability, different processes that affect that stability, and different policies that are deemed appropriate - i.e., the three kinds of assumption that, according to Holligan *et al.* (2002:10), differentiate each of the four myths of nature depicted in Figure 11. My point here is to argue that the fundamental beliefs, both about nature and about the human being, underlying geoengineering proposals need to be questioned if the social and ethical implications of these proposals are to be taken seriously. In fact, the fundamental issues of fairness, justice, and responsibility that are deemed important in the ethical debate on geoengineering can only be considered if we move beyond the dominant rhetoric of risk. From this perspective I could not be in more agreement with Hamilton:

> "The failure to appreciate the scale of the threat of climate change or to take in the Promethean nature of geoengineering is reflected in the question that —climate ethics believes it must answer, viz., what are the consequences for human wellbeing of transforming the earth‘s climate? It is not so much the anthropocentrism of the question that is of interest, but the unrecognized assumption about the kind of anthropos that asks such a question—a rational being who gathers evidence on the good and bad consequences, evaluates it and decides on how to act in a way that most improves human wellbeing. In short, climate ethics (including geoengineering ethics) is dominated by a consequentialist approach that naturally shies away from questions about how we ended up in this mess and what it means for humanity. In so doing, I will argue, it risks entrenching the very ways of thinking that lie at the heart of the climate crisis" (Hamilton, 2011: 2).

In this dissertation, I have presented and analysed two different frameworks within which to address the ethical issues in geoengineering (**PAPER III** and **PAPER IV**). The first represents the mainstream Earth system science perspective, while the second corresponds to an alternative view from the field of social studies of science and technology. Central to both is the concept of an epochal break, in the former in terms of the human-earth relationship, in the latter in terms of the relationship between science, technology, and society. I suggested that these two epochal breaks should constitute the fundamental axes from which a fully integrated history of geoengineering should be told and analysed. It is a history that not only places the evolution of this (and other) enterprise(s) in the context of a very long Earth history – **nature changed by human action** – but critically reflects upon it, to understand and interpret fundamental transformations in the relationships between science and society, science and nature, and science and technology – **changed nature of human action**.

Indeed, the history we are talking about is not only the history of geoengineering, the Anthropocene or the major epochal-making realignment of science and technology in society; it is the history of human action, in which scientists have become passionate protagonists of their individual beliefs, enlarging "the realm of human affairs to the point of extinguishing the time honoured protective dividing line between nature and the human world" (Arendt, 1958: 13). But because this capacity for action has become "the exclusive prerogative of the scientists" (Idem: 323), it lacks the revelatory capacity to illuminate the realm of human affairs in its specific phenomenal reality, and to endow this reality with meaning (Villa, 1996):

> "But the action of the scientists, since it acts into nature from the standpoint of the universe and not into the web of human relationships, lacks the revelatory character of action as well as the ability to produce stories and become historical, which together form the very source from which meaningfulness springs into and illuminates human existence. In this existentially most important aspect, action, too, has become an experience for the privileged few, and these few who still know what it means to act may well be even fewer than the artists, their experience even rarer than the genuine experience of and love for the world" (Arendt 1958, 324).

In the context of these "policy vacuums", characterised by "a growing sense of urgency coupled with a lack of knowledge of what to do and a lack of institutions where the issues could be addressed" (Rommetveit et al., 2010: 150), the recurrent claims that argue for a closer connection between science and society, with the purpose of exposing to public scrutiny the hidden assumptions, values and visions that are deeply embedded in science and technology, seem more than justified.

For science and technology studies (STS) the far-reaching implications of those claims rely on a set of "boundary concepts" (Irwin 2008), of which I highlight the concept of coproduction, that suggests that the "products of technoscience not only influence but also incorporate and reaffirm social values and institutional practices" (Jasanoff, 2011: 11), and which draws attention to "the often invisible role of knowledge, expertise, technical practices and material objects in shaping, sustaining, subverting or transforming relations of authority" (Jasanoff, 2004a: 4).

This explanatory power of thinking of natural and social order as being produced together leads the participatory ideals of public engagement, with all the reservations pointed out by Wynne (2007), far beyond narrow perspectives of problematising the relationship between science and democracy. Indeed, a more sophisticated model of public engagement with science (PES) and technology has been suggested for some time, one that acknowledges that "public engagement needs to move upstream" to consider new ways of listening to and valuing more diverse forms of public knowledge and social intelligence (Wilsdon and Willis, 2004; Felt and Fochler, 2009). The basic assumption underlying the notion of "upstream public engagement" relates with the necessity of replacing the one-way normative model of public "understanding" of (or "deference" to) science (Wynne, 2007: 100) to a more substantive model of engagement, which aims at creating more socially-robust scientific and technological solutions by way of opening up questions, furthering debates, exposing differences and interrogating assumptions.

The ultimate challenge is "to generate new approaches to the governance of science that can learn from past mistakes, cope more readily with social complexity, and harness the drivers of technological change for the common good" (Wilsdon and Willis, 2004: 24). What seems to be at stake is not only the need to clarify the assumptions and arguments that sustain the positions that tend to stick between hope and fear on science and technology – "For those promoting the technologies, such developments hold promises of a better world, for the sceptics they entail Faustian dangers and embody a lot of what is wrong with the modern world" (Hansen, 2010: 1) – but to go beyond these polarised positions to further explore the context of political uncertainty, public debate and societal decision-making in which science and technology have been operating (Irwin, 2008).

Against this background many authors have been arguing about the importance of considering public perceptions of geoengineering, thus helping to further unveil the perceived moral orders underlying these proposals (Bracmort et al., 2011; Miller, 2010a; Miller, 2010b; Cicerone, 2006; Pidgeon et al., 2012; Corner et al., 2012; Mercer et al., 2011; Rayner et al., 2013)

Therefore, in supporting the need to subject the scientific debate on geoengineering to a more open and critical reflection, I highlight the importance of rebuilding the "geoengineering scientific worldview" on social processes of trust and credibility, in this way impelling climate change science to better reveal competing social interests, values, and assumptions. I also see this as an opportunity to promote critical thinking about social problems that tend to be "circumvented" and reduced to technological fixes

(Weinberg, 1991), thus "alienating" and "diverting" our attention from an essential question, that of our place in nature.

5.2 Further Developments

An important direction for further research is already indicated above, and concerns the work that I have been developing in the last two years in order to engage the public at large in the online debate on geoengineering[71]. Some additional ideas for further research are indicated below. They are presented in the form of questions, as they arose in the course of this dissertation.

When I began this dissertation I had an initial meeting with my colleagues to present the scope and objectives of my project, and to discuss possible research paths. After I finished my presentation one of my colleagues presented several examples of human actions that, for some time now, have been changing the face of the Earth. Afterwards, he asked me whether those actions were substantially different from current geoengineering proposals - **What is new in geoengineering?**

I believe he was not expecting an answer, but rather trying to help me find the vantage point from which some fundamental questions regarding geoengineering could be raised. As if to attest its relevance, the question emerged several times throughout my investigation, suggesting the need to place the evolution of this human enterprise in the context of a much longer history. Now, that I am concluding this dissertation, I realise that probably the best approach to address this question is to investigate what is not new in geoengineering. And this leads me to a second question: **Is it possible to talk about the memories of emerging technologies, such as those of geoengineering?**

As discussed in **PAPER I**, the concept of geoengineering evolved from much earlier proposals to modify the climate. Accordingly, some authors who have been studying the history of weather and climate modification emphasise the importance of looking at geoengineering holistically — "of integrating social considerations with technical

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[71] https://sites.google.com/site/geoengineeringdebate/

promise, and scientific study with human and moral dimensions" (Bonnheim, 2010: 891). From this perspective, exploring the affinities between climate engineering proposals and many past technologies may bring new insights into the social and ethical implications of geoengineering. For instance, the idea of terraforming, which once informed dreams about exploring and exploiting other planets, seems to have been reinvented under the aegis of Earth system science to re-centre on Earth itself the proposals for the wholesale rearrangement of a planet's environment to support human life. Like space exploration in the 1970's and 1980's, geoengineering proposals challenge the basic concept of limits that underpins the environmental movement, holding out new prospects for enhancing and expanding our current lifestyles.

The memories of past technological innovations may not only expand the range of moral issues deemed important to geoengineering, but can also add considerable depth to the discussion about the conditions that must be satisfied if geoengineering is to proceed ethically and responsibly. Therefore, I suggest these memories should be seen as an essential part of the proposed approaches to govern geoengineering research. And this leads me to a third question: **How can we maintain an active memory of the past in new areas of research and innovation?**

The concept of "Responsible Research and Innovation" marks the recent evolution of the European Commission's Science in Society Programme and translates its focus on the development of more integrative approaches throughout the whole innovation process. Engaging the stakeholders in early stages of research and seeing "ethical considerations not as constraints, but as drivers from innovation" (Schuurbiers et al., 2014: 6) are two key aspects that lie beneath this concept.

According to Owen *et al*. (2013: 36) "responsible innovation is a collective commitment of care for the future through responsive stewardship of science and innovation in the present". Four dimensions of responsible innovation have been identified in the context of this broad definition:

- **anticipatory** - describing and analysing those intended and potentially unintended impacts that might arise, be these economic, social, environmental, or others.
- **reflective** - reflecting on underlying purposes, motivations, and potential impacts, what is known and what is unknown, associated uncertainties, risks, areas of ignorance, questions, and dilemmas.
- **deliberative** - inclusively *opening up* visions, purposes, questions, and dilemmas to broad collective deliberation through processes of dialogue, engagement, and debate, inviting and listening wider perspectives from publics and diverse stakeholders.
- **responsive** - using this collective process of reflexivity to both set the direction and influence the subsequent trajectory and pace of innovation, whilst focussing on effective mechanisms of participatory and anticipatory governance.

An explicit reference to the present and the future is contained in this definition of responsible innovation and implicit in its four dimensions– "which when integrated together may allow such a commitment of care and stewardship to be enacted" (Idem: 37). Although no explicit reference is made to the past, these four dimensions suggest the important role past memories play when reflecting and deliberating on both the "products" and "purposes" of (von Schomberg, 2011) science and innovation. Furthermore, the idea of collective commitment presupposes an account of the history of the institutions to which one belongs, and which shape who one is. In fact, as Grinbaum and Groves suggest "collective political responsibility rests on historical continuity, flowing from the past and reaching out to embrace the future" (2013: 133).

It is in line with this notion of collective political responsibility that I argue that an active memory of the past should constitute a key part of the comprehensive governance framework for responsible research and innovation. Three assumptions sustain the important role I believe memory (and forgetting) play in the processes of research and innovation:

- First, that the turn towards memory and the past involves not only the attempt to secure the future, but also the no less perilous task of taking responsibility for maintaining an active memory of the past (Huyssen, 2003: 16).
- Second, that learning from experience (including the lessons learnt from past mistakes) must constitute a key aspect of the strategies which have been proposed for strengthening Responsible Research and Innovation. This is so not only "for the instrumental reasons of avoiding harmful mistakes, but also for the democratically-accepted legitimacy of our institutions of policy and politics, and of the science which shapes these" (Felt et al., 2007: 64).
- Third, the need to subject the commitments to a particular knowledge-trajectory to more critical and open reflection, insofar as these commitments carry with them epistemological consequences, and responsibilities about the "unlearning processes", i.e. "the non-pursuit of alternative possible knowledge-trajectories that could have been developed" (Idem: 67).

Thus, by sharing the view that "narratives teach continuity and comparison", and that it is "through developing such reflective skills about the cultural meaning of innovation that the virtue of responsibility can be developed" (Grinbaum and Groves, 2013: 139), I intend to further explore the narratives of geoengineering, so as to bring to light the limits of foresight and rational prudence and the concomitant implications for responsibility.

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PART 2

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Geoengineering

Reflections on Current Debates

PAULA CURVELO AND ÂNGELA GUIMARÃES PEREIRA

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Geoengineering: Reflections on Current Debates

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Abstract: In this paper we propose to investigate the current debates on geoengineering, here considered as an illustrative metaphor of particular technoscientific promises and 'techno-fix' narratives that are emerging in our society. After a brief introduction, where we provide the necessary background to understand the complex issues surrounding geoengineering, we discuss the relevance of this investigation. We then proceed to explore the controversies behind geoengineering, which start with its own definition. The analysis of the current debates around geoengineering experimentation, regulation and deployment reveal some of the dominant narratives of technoscientific progress and highlight important tensions and frictions in the relationship between science, policy and society. A reflection on these issues suggests the relevance of developing alternative approaches to furthering the 'democratisation and de-alienation' of geoengineering debates, thus responding to a perceived need for more careful consideration of the normative assumptions that lie behind the idea of deliberately manipulating Earth's climate to offset anthropogenic climate change.

Keywords: Climate Engineering, Geoengineering Debates, Climate Change, Narrative Inquiry, Master Narratives

Introduction

The idea of weather modification and climate manipulation is not new, nor is it associated with a particular discipline, branch of knowledge or area of expertise. For this reason, the (hi)story of geoengineering – i.e. 'the deliberate large-scale intervention in the Earth's climate system in order to moderate global warming' (The Royal Society 2009) – may have different beginnings, may explore (or omit) a variety of episodes and may be told from a particular point of view. These 'qualities' are visible in the fairly recent literature on the topic, where we find a variety of references introducing and contextualising the emergence of geoengineering technologies: the image of Ulysses assisted by, or being a victim of, deliberate weather modification schemes brought about by various gods and goddesses; the tempest conjured up by Prospero in William Shakespeare's play of the same name (Schneider 1996); the diabolical plan to tilt the Earth's axis and melt the polar ice in Jules Verne's novel *The Purchase of the North Pole* (Fleming 2006); the various attempts at artificial rainmaking (Fountain 2003, Fleming 2010, 2007), in what Robert DeCourcy Ward called the stage of 'production' (Ward 1930); the weather control fantasies of military planners and the way these visions shaped some of the weather modification programmes in the Cold War era (Bonnheim 2010, Fleming 2010, 2006, Keith 2000); the common links with the concept of 'terraforming' (Fleming 2010, Yanarella and Rice 2011) and the way its literature (both scientific and fictional) is trying to fill the gaps that still exist in geoengineering literature (Keith 2000).

These are but a few examples of the ubiquitous and eclectic ideas that, in some way, share a common theme with current geoengineering proposals: that which relates human expectations, fears and fantasies with the recurring appeal of the control of nature. Hence, even though some may appear unconnected with the history of geoengineering, such ideas are nonetheless useful in reminding us that recent proposals to geoengineer the climate are just one contemporary manifestation of man's long-standing desire to control nature – an early-twenty-first-century embodiment of the 'Baconian project' of human mastery over nature.

By looking at 'the long history of deceptive and delusional attempts to control nature', Fleming identifies three cycles 'of promise and hype' that capture the pathological features of weather and climate control schemes (Fleming 2006, 2007).

The first cycle, the 'Pluviculturalists', began in the 1840s with the work of the meteorologist James Pollard Espy, who propounded a theory of artificial rainmaking by lighting huge fires.

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The second cycle, ‘Cloud seeding in the Cold War and Vietnam War eras’, began in 1946 with the pioneer experiments in cloud seeding by Irving Langmuir and his associates at the General Electric Research Laboratory, which rapidly evolved from lab science experiments to commercial rainmaking applications, and ultimately ‘the attempted weaponization of the clouds’ (Fleming 2006).

Three decades later, the term geoengineering was coined by the physicist Cesare Marchetti to describe a proposal for tackling the problem of CO_2 control in the atmosphere with a CO_2 management system, where ‘CO_2 is collected at proper fuel transformation points and finally injected into the deep seas taking advantage of natural thermohaline circulations’ (Marchetti 1977, vi). Almost at the same time, on the other side of the globe, the Russian climatologist Mikhail Budyko was probing the potential of different techniques to modify the aerosol layer of the stratosphere to prevent the warming of the climate (Schneider 1996, Bonnheim 2010, Budyko 1977).

However, it was only at the beginning of this century that geoengineering entered the mainstream debate on climate change. According to Fleming, the beginning of the third cycle, ‘Weather modification in the 21st century’ – in which ‘discussion of weather and climate modification has returned to the science-policy agenda, framed as seemingly inevitable responses to killer storms and global warming’ – coincides with the publication of the U.S. National Research Council report titled “Critical Issues in Weather Modification Research” (National Research Council 2003), and the report commissioned by the U.S. Pentagon, “An Abrupt Climate Change Scenario and its Implications for United States National Security” (Schwartz and Randall 2003). But perhaps the most important impetus came in 2006, with the publication of an editorial essay by Nobel laureate Paul Crutzen in the journal *Climatic Change* (Crutzen 2006) that brought discussions of geoengineering more squarely into the focus of scientific debates (Roger Pielke Jr. 2010).

Yet, to fully understand these events, we have to consider them in the context of increasing doubt and disbelief regarding the commitment of the international community to adequately respond to the problem of global warming. In fact, throughout the 21st century, the geoengineering discourse has been closely coupled with the climate change agenda, being affected by its major convulsions in the scientific and political arenas.

Lastly, the continued misunderstanding and disbelief in the science of climate change, the recognition that global warming is the net result of various institutional failures, and the recent tendency to favour transformational (rather than incremental) responses to this problem, appear to have combined with the major uncertainties of climate change to provide the conditions for geoengineering to emerge as a paradigmatic case ‘where facts are uncertain, values in dispute, stakes high and decisions urgent’ (Funtowicz and Ravetz 1993, 1994a).

Exploring Geoengineering Debates

Though the idea of weather and climate control is not new, the purpose and extent of climate modification proposals since the beginning of this century seem to have overtaken the original concepts and the scientific questions from which they arose, and have been appropriated by the competing interests that surround climate change science.

The environmental problems and scientific uncertainties that many of the climate engineering schemes evoke are being brought to the centre of the climate change debate, feeding environmental controversies and bringing to light value disputes at the same time as the discourse becomes more and more politicised (Sarewitz 2004).

Against this background, the analysis of geoengineering debates may contribute not only to uncovering the variety of knowledge, values and interests that compete in the climate change science, but also to mapping the dynamics of these debates in the context of the major narratives that are emerging in our society — thus seen as a valuable approach to understanding the mutual co-production of science and society, in which 'scientific knowledge both embeds and is embedded in social identities, institutions, representations and discourses' (Jasanoff 2004).

In this context, approaching geoengineering in a holistic manner is another way of looking at the problem of climate change and the 'scalar dislocations' it introduces in modern systems of experience and understanding (Jasanoff 2010). In fact, the ethical, political, environmental and social considerations that surround the debates on geoengineering seem to offer a privileged perspective for rethinking the human place in nature.

Debates around the Definition of Geoengineering

We start the analysis of current debates on geoengineering by focusing on the major disputes around the definition of geoengineering – a term on which the scientific community seems far from reaching a consensus, as has been pointed out by several authors and was made clear in the 2011 IPCC expert meeting on geoengineering.

> 'A substantial amount of time in the Expert Meeting was spent in discussing terminology in and around geoengineering. This underlines the ambiguities associated with the term geoengineering and the range of opinions on the subject' (Boucher, Gruber, and Blackstock 2011, 2).

In fact, many of the controversies surrounding geoengineering start with the lack of consensus regarding the broadness and significance of the term. A look at the recent literature on the topic (scientific articles, books, policy reports and media articles) reveals two major sources of disagreement. The first of these is the different meanings attributed to the term. One example of this may be seen in the confrontation between those authors that suggest that we began geoengineering the Earth's climate when we started causing significant disturbances to the planetary environment (resulting in a definition of geoengineering closely related to that of the 'Anthropocene'[1] (Crutzen and Stoermer 2000)), and those espousing definitions that highlight the particular characteristics of the actions carried out with different climate engineering techniques.

> 'In its broadest sense, geoengineering involves deliberately modifying the Earth system and its processes to suit societal needs and improve the planet's habitability. During recent years, discussions of this controversial concept have been confined largely to global-scale engineering approaches intended to counteract the effects of anthropogenic climate change. Proponents of geoengineering point out that humans have been modifying the Earth system and its processes unintentionally for some time; therefore, why not do it in a deliberate manner with specific goals in mind?' (Greene, Monger, and Huntley, 2010).

As the above quotation suggests, a broad definition of geoengineering tends to underestimate the arguments against the most controversial schemes to modify the energy balance of the atmosphere. By contrast, a narrow definition of the term highlights the intentionality of geoengineering actions, thus calling for a critical examination of the ethical, social, and political issues raised by these proposals.

But even if general agreement could be achieved on the particularities of geoengineering actions, the different types of proposals that the term encompasses seem to be a second source of

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[1] Paul Crutzen and Eugene Stoermer coined the term *Anthropocene* to describe a new geological epoch, '*in which humankind has emerged as a globally significant — and potentially intelligent — force capable of reshaping the face of the planet*' (Clark, Schellnhuber, and Crutzen 2004) .

fuzziness more difficult to address. To illustrate this, we briefly present the two different families of methods into which geoengineering schemes are usually classified (The Royal Society 2009):

i. Carbon Dioxide Removal (CDR) methods, which aim to reduce the concentration of CO_2 in the atmosphere and transfer it to long-lived reservoirs, and
ii. Solar Radiation Management (SRM) methods, which aim to reduce the amount of solar energy absorbed by the Earth.

The first family of methods includes large-scale engineering approaches, which use either chemical or physical processes to directly remove CO_2 from the atmosphere or the oceans, (e.g. engineered air capture and enhanced weathering techniques), and biologically-based methods seeking to simulate or enhance natural carbon storage processes (e.g. afforestation and reforestation, biomass and biochar, ocean fertilisation methods, among others).

The second family of methods includes some of the most controversial geoengineering proposals. Four groups of techniques have been proposed to reduce the incidence and absorption of incoming solar radiation: i) *Space-based approaches* – reducing the amount of solar energy reaching the Earth by positioning sun-shields in space with the aim of reflecting or deflecting solar radiation; ii) *Changes in stratospheric aerosols* – injecting sulphates or other types of particles into the upper atmosphere, with the aim of increasing the scattering of sunlight back to space; iii) *Increases in cloud reflectivity* – increasing the concentration of cloud-condensation nuclei in the lower atmosphere, particularly over ocean areas, thereby whitening clouds with the aim of increasing the reflection of solar radiation; and iv) *Increases in surface albedo* – modifying land or ocean surfaces with the aim of reflecting more solar radiation out to space (The Royal Society, 2009; Williamson et al. 2012, p.26).

As this brief overview suggests, the different technological characteristics of these proposals, the different costs estimated for each method, the potential efficacy of their use, the levels of uncertainty associated with their deployment, and the distinctive risks they raise result in a multitude of solutions that seem difficult to bring together under the broad umbrella of the term geoengineering.

One of the first attempts to clarify the ambiguity of the term was made in 1996 by Thomas Schelling, who identified the features that geoengineering seems to imply: global, intentional and unnatural interventions (Schelling 1996). Four years later, David Keith took this proposal further by pointing to the three core attributes that serve as ‘markers of geoengineering’ actions: the scale (global or continental), the intent (the deliberate nature of the action rather than a side effect of it) and the degree to which the action is a countervailing measure (Keith 2000). The reasons for replacing ‘unnatural’ features by the ‘degree to which the action is a countervailing measure’ were not properly explained − even though this had implications for the type of proposals that the term encompasses[2].

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[2] In order to exemplify these implications it seems appropriate to refer briefly to the use of weather modification techniques (such as cloud seeding and hurricane suppression) that are taking place in many countries around the world. As recently stated by the World Meteorological Organisation: ‘*since the 1980’s there has been a decline in support for weather modification research, and a tendency to move directly into operational projects*’ (WMO 2010). Given the similarities between weather modification (WM) techniques and some geoengineering methods, the concerns raised by the increasing number of WM operational programmes (fog dispersion, rain and snow enhancement and hail suppression) have gained momentum in the context of the contemporary debates on geoengineering — leading, almost inevitably, to a discussion on the criteria that differentiate these two domains. However, although widely mentioned, the scale marker seems to be insufficient to exclude WM techniques from the vast range of methods that the term geoengineering encompasses. This becomes clear from the way the ‘countervailing measure criterion’ has been evoked, namely by drawing attention to the differences between ‘weather’ and ‘climate’ modification techniques, and to the far-reaching consequences of the latter: ‘*Weather modifications such as cloud seeding which affect the weather for no longer than a season, in our view, do not fall within the definition of geoengineering (…) We conclude that weather techniques such as cloud seeding should not be included within the definition of geoengineering used for the purposes of activities designed to effect a change in the global climate with the aim of minimising or reversing anthropogenic climate change*’ (UK House of Commons. Science and Technology Committee 2010, 15). Nonetheless, it is telling that according to this same report: ‘*Cloud seeding could affect climate when carried out over a long period*’ (Idem).

Nevertheless, these three markers seem to translate the meaning of the term geoengineering as commonly used by the scientific community nowadays, furthering the conceptual distinction between geoengineering proposals and other responses to climate change.

However, in considering the ethical issues raised by these technologies, it becomes clear that these markers tend to hinder the various values, rationales and normative assumptions underlying the range of CDR and SRM techniques considered under the broad umbrella of the term geoengineering. As mentioned by Gardiner, the ethical discussion of geoengineering is made more difficult by the complexity of the terrain:

> 'First, a number of interventions are already being proposed for combating climate change, and it is not clear that all of them should be classified together. For example, some suggest deflecting a small percentage of incoming radiation from the Sun by placing huge mirrors at the Legrange point between it and the Earth, some advocate fertilizing the oceans with plant life to soak up more carbon dioxide, some suggest a massive program of reforestation, and some propose capturing vast quantities of emissions from power plants and burying them in sedimentary rock deep underground. But do these interventions raise the same issues? Should we count all of them as "geoengineering"?' (Gardiner 2010, 285).

To overcome the obstacles raised by the broadness of the term, Bunzl appeals to the methodological distinction between small 'g' proposals and big 'G' proposals[3]. According to the author, this distinction is fundamental to deconstructing some of the common arguments for advancing further and faster in geoengineering research. In fact, because big 'G' proposals fall into a specific class of scientific endeavours (where the object of interest is not 'modular' or 'encapsulated'), they generate a set of methodological challenges, allowing the moral argument as to 'whether research should be done' to give way to the methodological argument as to 'whether it could be done' — thus shifting the burden of proof to the proponents of geoengineering.

> 'But what if the object of your interest is not modular or encapsulated? What do you do then? For that, after all, is the feature that big "G" geoengineering proposals have in common. They call for interventions on systems that lack just this characteristic. You cannot encapsulate part of the atmosphere and it is too complex to be able to build a realistic non-virtual model at scale. As such, it is reasonable to ask whether we could ever have a sound basis for moving to full deployment of any such proposed intervention. And if not, then why bother to even research such proposals in the first place?' (Bunzl 2009, 2).

It seems most reasonable to question the feasibility of geoengineering research in light of its object of interest. Indeed, the pressure of practice under which science operates today (Carrier 2011) is giving rise to the emergence of new objects of research – ambivalent beings, hybrid products and theoretically constructed objects through which we gain a new understanding and control of nature – that call for a more careful consideration of the complex narratives and practices of science and technology (Funtowicz and Ravetz 1993, 1994b, Latour 1987, Law 2002, Haraway 1997, Michael 2006).

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[3] '*Of course there is geoengineering and then there is GEOENGINEERING. Nobody gets very wound up about the idea of planting trees or painting roofs white as instances of geoengineering — which is not to say that they will necessarily do much good. The kind of geoengineering that elicits howls of disapproval is grander than this — it is things like space mirrors, sulphur injection into the upper atmosphere, and iron fertilisation of the oceans — it is the idea of intervention on a grand scale*' (Bunzl 2009).

Following this appeal, some authors have suggested that it is precisely at the level of these objects of research that we can find the meaningful distinction between science and technoscience, an ontological difference that 'becomes more explicit when research results are presented in particular settings and when the objects of research are exhibited for the specific interest they hold' (Bensaude-Vincent et al. 2011, 365). Accordingly, and by way of illustration, it could be said that when the result of a global climate model experiment is presented as scientific evidence for understanding the role of aerosols in climate forcing, this would conform to traditional conceptions of science. However, when sulphate aerosols are presented for their capacity to counteract the climate forcing of growing CO_2 emissions, this should be seen as a 'hallmark of technoscience'.

As we will see next, many of the controversies surrounding geoengineering go beyond the ambiguities of the term. However, and as pointed by Bunzl, some important questions regarding the research, governance and deployment of these technologies can only be properly answered if we consider the significant differences between the multitude of proposals that the term encompasses.

Unveiling the Multiple Narratives behind Geoengineering Discourses

An overview of the subject of geoengineering may be extremely illustrative, but also bewildering, with regard to the controversies that the term encompasses. At first glance, one may be frightened by the revisited version of Edvard Munch's 'The Scream' on the cover of the report of the ETC Group, entitled 'Geopiracy – The Case Against Geoengineering' (ETC Group 2010). Perhaps one may also find this reference in a suggested comparison between the way the Krakatoa eruption inspired Munch to create this work and the way the eruption of Pinatubo inspired geoengineers to cool the Earth (Hamilton 2010). One may come across the variety of histories that feed 'chemtrails' theories[4], or one of the scientific studies that compare different geoengineering options (Keith and Dowlatabadi 1992, Keith 2000, National Research Council 1992, Vaughan and Lenton 2011). By chance, one may stumble over a few of the various attempts to rank these options: some evocative but difficult to assess (Adam 2009), others suggesting a scientific asset (Boyd 2008, Lenton and Vaughan 2009, The Royal Society 2009), and yet others being sarcastic about this last possibility (Singer-Vine 2010). Lastly, one will most likely end up with Meinrat Andreae's decadent image of our society's addiction to fossil fuels, 'It's like a junkie figuring out new ways of stealing from his children' (Morton 2007), or with one of the many meaningful terms that populate the geoengineering world: 'back-up plan' (Inman 2010); 'catastrophic climate change'(Gardiner 2011, Hegerl and Solomon 2009); 'climate anxiety' (Bonnheim 2010); 'covert geoengineering' (Lawrence 2006); 'emergency brake' (Brovkin et al. 2009); 'fallback strategy' (Keith 2002, Keith and Dowlatabadi 1992); 'geohack' (Singer-Vine 2010); 'global thermostat' (Goodell 2010); 'planet-hacking techniques' (Kintisch 2010); 'planetary medicine' (Lovelock 2008, 2009); 'predatory geoengineering' (Gardiner 2011); 'retooling the planet' (Bronson, Mooney, and Wetter 2009); 'stopgap' (Barrett 2008, Bunzl 2009); 'technological fix' (Montenegro and Greenwood 2009)...

Despite the confusion a first glance may suggest, a more detailed analysis of the literature in the field may be extremely valuable in understanding the particular kinds of knowledge, values and interests that are competing in the climate change debate and in uncovering some of the dominant narratives that operate at different levels of society.

One reasonable and logical way of digging through the debates on geoengineering is 'to collect, structure, and relate the very different arguments that have been advanced for and against climate engineering' (Rickels et al. 2011): the 'moral hazard argument' (The Royal Society

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[4] The term 'chemtrail' is derived from 'chemical trail' and specifically refers to chemical or biological agent trails left by aircraft for a purpose undisclosed to the general public, allegedly causing respiratory illnesses and other health problems.

2009); the ‘the slippery slope’ argument; the ‘technical fix’ argument; the ‘unpredictability’ argument (Keith 2000); the ‘lesser evil’ argument; the ‘arm the future’ argument, the ‘cost-effectiveness’ argument; the ‘research first’ argument; the ‘stalking horse’ argument (Gardiner 2010, Gardiner 2011); the ‘common sense’ argument (Jamieson 1996); the ‘desperation argument’ (Gardiner 2012), etc. These different arguments tend to be linked around the main theses that have been identified in the debate on the pros and cons of geoengineering research and deployment (Betz and Cacean 2012, Rickels et al. 2011) and illustrate the diversity of attempts in this area. Many of these arguments emerge in the debates in and around the ‘grey zones’, or interfaces, between science, policy and society (Siune et al. 2009), and can be grouped, for systematisation purposes, into three interconnected domains: i) geoengineering research and experimentation; ii) geoengineering regulation and governance, and iii) geoengineering implementation and misuse (Figure 1) .

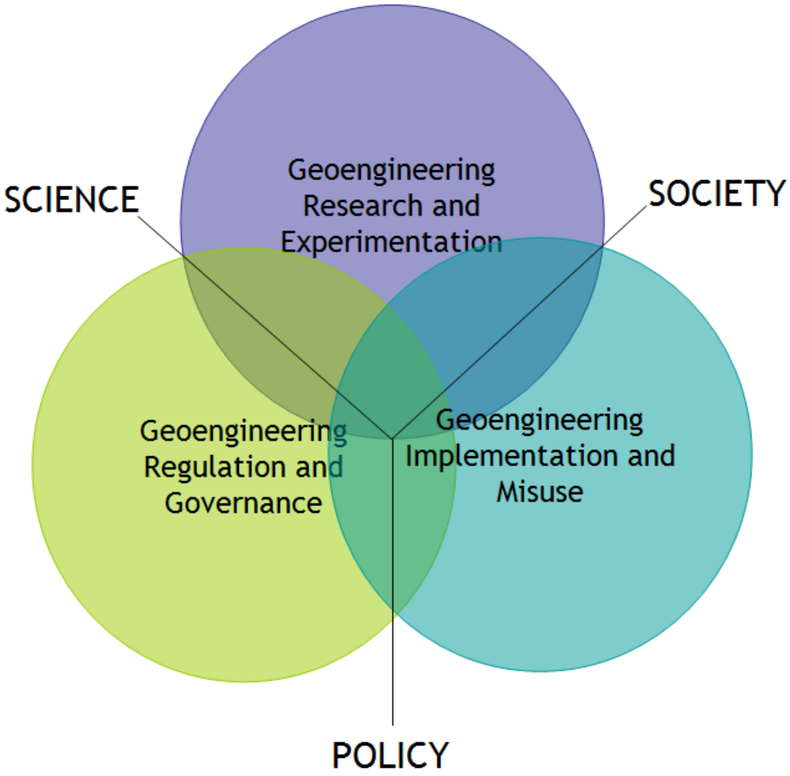

Figure 1– Domains within which Current Debates on Geoengineering Can Be Grouped

Geoengineering Research and Experimentation

In this first domain, we have identified some of the most active disputes over geoengineering, which is not surprising given that research is the stage where much of the geoengineering proposals currently are at and experimentation is the expected next step. The construction of the arguments varies, but in general they fall into three major groups:

i) The first group holds that geoengineering, along with mitigation and adaptation, is a valid and unavoidable response to climate change, so we must invest in geoengineering research in order to be prepared for a likely climate emergency:

> ‘The rate of increase of climate change, along with the continuing increase in emissions of greenhouse gases, has created a very serious predicament for the world. Drastically reducing the world’s use of fossil fuels will take time and may raise near-term costs for energy, even after the effort gets seriously started and production costs for new energy technologies drop. As a result, global warming is likely to press up against or even exceed the level that the Commission of European Communities, for example, has concluded is likely to lead to dangerous and unacceptable consequences. For this reason, it seems prudent for the nations of the world to initiate an effort in geoengineering (...)’ (MacCracken 2009, 33).

This argument finds its support in two inter-related narratives of technoscientific progress that tend to shape and frame key dimensions of science and governance: the risk of dismissing a ‘promising technology’ and the ‘speed imperative’ that impels us to act immediately ‘before it is too late’ (Felt et al. 2007). Furthermore, this argument often appears coupled with another, that of the ‘incredible economics of geoengineering’ (Barrett 2008).

ii) The second group, and perhaps the most significant, regards geoengineering with reserve but considers it would be a mistake to ban geoengineering research without first reducing the uncertainties surrounding the associated benefits and risks, claiming that it is premature to discard these options without carrying out adequate, though ‘moderate’, research into the topic (Blackstock and Long 2010, Blackstock et al. 2009, Robock 2008, 2011).

> ‘The reasons why geoengineering may be a bad idea are manifold, though a moderate investment in theoretical geoengineering research might help scientists to determine whether or not it is a bad idea’ (Robock 2008).

This strong argument is sustained by the new credo of ‘evidence-based’ decision making, where facts must precede any exercise of values.

iii) The third group comprises arguments against geoengineering research – particularly research into SRM methods. The arguments are of two kinds:

- those opposing geoengineering solutions on principle, on the basis of the common sense belief that ‘two wrongs do not make a right’, and
- those challenging the soundness of the arguments in favour of geoengineering research, in this way trying to deconstruct some of the narratives on which they are based.

Since the first kind of argument concerns the validity of geoengineering solutions, it does not directly address the specific case of geoengineering research (which is assumed to be as doubtful as the concept itself). Here, we can find many of the arguments that try to demolish the ‘techno-fix’ ideas behind geoengineering solutions: SRM methods do not address the root cause of anthropogenic climate change; geoengineering is ‘unnatural’ and SRM technologies are objectionable (Jamieson 1996, NERC 2010a, b); we have to find a place consistent with the limits of nature (Bunzl 2009) and technology cannot replace the process of ‘social engineering’ (Weinberg 1991) that this goal implies.

The second kind of argument against geoengineering research tends to emerge in the ethical discussion of the subject (Keith 2000, Gardiner 2011, Bunzl 2009, Victor et al. 2009, Jamieson 1996, Hamilton 2013). Morrow, Kopp and Oppenheimer present a clear synthesis of these arguments:

> ‘There are four ethical reasons to worry about performing climatic SWCE[5] research at all, over and above its effects on humans, animals, and ecosystems. First, pursuing

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[5] In this paper the authors refer to SRM as “short-wave climate engineering” (SWCE).

> SWCE solutions to climate change may create a moral hazard, exacerbating the challenge of mitigating emissions. Second, SWCE research may lead to development of technologies that could be used for nefarious purposes. Third, beginning SWCE research in earnest may create interest groups within scientific or business communities that would have strong incentives to push for SWCE (or at least SWCE research) even if it turns out to be unwise. Finally, money spent on SWCE research is unavailable for other kinds of research, such as on the mitigation of or adaptation to climate change' (Morrow, Kopp, and Oppenheimer 2009).

Discussions about governance mechanisms and basic principles to guide future geoengineering research tend to highlight the profound reorientation of technoscientific practices in contemporary societies – of what has been seen as a major shift from the 'laboratory ideal' to the 'field ideal' of experimentation (Schwarz and Krohn 2011). Indeed, the recognition that 'several geoengineering technologies are demonstrably non-encapsulated' (Bracmort and Lattanzio 2013, 5) tends to further polarise the debate. On the one hand, those who call for 'a moratorium on all geoengineering activities outside the laboratory' (ETC Group 2010, 40). On the other hand, those who consider that the 'least risky option would involve starting with small-scale field experiments and gradually ramping up the scale' (Eccleston and March 2011, 358).

> 'Another key question is how to address further research. Proponents of further research argue that it is needed in order to obtain reliable information about the feasibility and risks. However, this would at some stage require real-world field experiments that would have to be gradually scaled up in order to know the impacts of a particular technique and whether it is effective. Apart from the difficulty of drawing the line between research and deployment, most existing rules of international law do not make this distinction' (Bodle 2013, 468).

And once again, Morrow, Kopp and Oppenheimer provide an interesting point of view on this subject, introducing the 'narrative of ethics' to the debate, and suggesting that climatic SWCE research[6] is very similar to nuclear weapons testing. They thus propose careful ethical consideration guided by three principles derived from the ethics literature on research with human and animal subjects:

> 'The Principle of Respect requires that the scientific community secure the global public's consent, which would need to be voiced through their representatives and given for any studies within specified parameters, rather than on a case-by-case basis. The Principle of Beneficence and Justice requires that researchers strive for a favorable risk-benefit ratio and a fair distribution of risks and anticipated benefits, all while protecting the basic rights of the individuals affected. Finally, the Principle of Minimization requires that no study last longer, cover a greater geographical extent, or exert a greater influence on the climate than is necessary to test the specific hypotheses in question' (Morrow, Kopp, and Oppenheimer 2009, 1).

A similar position was articulated in the "Oxford Principles", a set of five overarching principles for governance of geoengineering research: (i) geoengineering to be regulated as a public good; (ii) public participation in geoengineering decision-making; (iii) disclosure of geoengineering research and open publication of results; (iv) independent assessment of impacts; and (v)

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[6] According to the authors, other kinds of climate engineering research (such as modelling studies and engineering studies) do not raise the same concerns as climatic studies – which aim '*to determine the climatic response to climate engineering and therefore could have widespread impacts on both human populations and the biosphere'*.

governance before deployment (Rayner et al. 2013, Rayner et al. 2009). This leads us to the second domain of the geoengineering debate: that of geoengineering regulation and governance.

Geoengineering Regulation and Governance

In this second domain, the debate revolves around two main concerns: the need i) to regulate specific geoengineering activities (large-scale research projects, small-scale field tests, field experiments, trial deployment and implementation) and ii) to balance carefully the technical, legal, ethical, economic and social concerns in a policy and governance framework, which is ‘international in scope and remains flexible in light of fresh evidence’ (The Royal Society 2009). If the first domain suggests that we are in the sphere of geoengineering science, here we feel we are crossing into the sphere of geoengineering politics:

> ‘As geoengineering is considered more seriously, the question of norms to govern deployment will arise. Norms might be needed not only to determine when such systems might be used but also the kinds of evaluations that geoengineers might be required to make before deployment, compensation for parties harmed, cost sharing, and commitments to maintain geoengineering systems once deployed’ (Victor 2008, 330).

In fact, in this second domain the debate tends to move from the functioning of science to its interactions with policy and society, particularly by exploring three major narratives:

i) The narrative of ethics, which introduces the questions of public value into the geoengineering field to overcome the difficulties of ensuring ‘citizen representation’ and the concerns of legitimacy associated with this (thus providing the basis for discussing the permissibility of the most controversial schemes and becoming an important legitimising factor for geoengineering activities). In the debate on geoengineering regulation and governance, this narrative focuses primarily on the concepts of fairness and justice, drawing upon formulations of environmental ethics and ethical and legal guidelines for human and animal subjects research (Miller 2010a, Morrow, Kopp, and Oppenheimer 2009, Keith 2002):

> ‘Yet, for me, phrases like “legitimate international process” and “all stakeholders” sound too much like climate scientists and government diplomats getting together to decide the fate of the planet. That hasn’t worked so well so far, and not only because vulnerable developing countries have not been adequately consulted. So what kind of governance process do we need? To my mind, a potentially potent analogy is that of informed consent in human subjects research. Just like geoengineering research, human subjects research brings potentially significant public and private benefits by alleviating disease, injury, and even death. Yet, because such research is also very dangerous, societies have adopted strict regulations for the conditions under which that research can be done’ (Miller 2010a).

ii) The narrative of failure, which spotlights the side effects and unintended consequences of geoengineering proposals, and therefore calls for the adoption of precautionary approaches and global, transparent and effective control and regulatory mechanisms. This narrative informs the politics of geoengineering, being particularly evident in the discussion of the risks surrounding field experiments with such technologies, concerns about unilateral attempts to conduct large-scale geoengineering actions, and the way they may weaken conventional mitigation and adaptation efforts, in what is referred to as the ‘moral hazard’ argument:

> ‘In the context of geoengineering, the risk is that major efforts in geoengineering may lead to a reduction of effort in mitigation and/or adaptation because of a premature

> conviction that geoengineering has provided ‘insurance’ against climate change’ (The Royal Society 2009, 37).

iii) Lastly, the ‘valid science’ narrative, suggesting possible ways to promote further ‘strategic research’ in the geoengineering field, the establishment of appropriate institutions for geoengineering governance, and greater citizen involvement, and calling for climate change science to become more critically reflective about its own role and impact. The ‘valid science’ narrative, appears under different forms on discourses of geoengineering regulation and governance, being particularly prominent in the debate on the involvement of relevant international scientific organisations, the establishment of international bodies and the first attempts to devise possible configurations to govern the research and deployment of geoengineering technologies (Olson 2011, Bodansky 2011, 2012, Bracmort and Lattanzio 2013).

> ‘Meaningful research may also require actual trial deployment of geoengineering systems so that norms are informed by relevant experience and command respect through use. Standard methods for international assessment organized by the Intergovernmental Panel on Climate Change (IPCC) are unlikely to yield useful evaluations of geoengineering options because the most important areas for assessment lie in the improbable, harmful, and unexpected side effects of geoengineering, not the 'consensus science' that IPCC does well’ (Victor 2008, 321).

Together, these intertwined narratives tend to invoke the concept of ‘good governance’, which refers to the ‘principles of openness, participation, accountability, effectiveness and coherence’, and the need for science to function properly, i.e. ‘assuring the productive functioning of its endeavours, and the maintenance of scientific integrity’ (Siune et al. 2009).

Geoengineering Implementation and Misuse

The third domain includes the discussions surrounding the benefits and risks of using geoengineering to counteract global warming. While on the one hand we are still in the domain of empirical science, surrounded by simulation models that seek to address the climatic consequences of geoengineering schemes (Matthews and Caldeira 2007, Lenton and Vaughan 2009) and attempts to assess and rank different geoengineering methods – in terms of efficiency, affordability, safety, controllability, timeliness, reversibility, among others (The Royal Society 2009, Vaughan and Lenton 2011, Boyd 2008, Bellamy et al. 2012) – on the other hand we are also in the domain of ‘geoengineering plausibility’, where expectations, fears, fantasies, beliefs, and, of course, scientific expertise conspire to produce visions of *geoengineered worlds*.

The discourses about geoengineering implementation range from expert reviews that examine the potential advantages, drawbacks and risks of the different schemes to recent participatory processes that seek to elicit public and/or stakeholder views and perceptions of geoengineering (Bellamy et al. 2012). In these discourses we find many of the narratives previously identified, now being used to fill the empty spaces left by the inherent uncertainties associated with geoengineering technologies and climate change science. The positions vary and are not consistent with the traditional divisions usually found in the climate change debate — a ‘quality’ of the geoengineering debate that was already stressed by Dale Jamieson in 1996:

> ‘The recent debate makes for strange bedfellows. Many of those who believe most strongly that climate change is occurring are reluctant to embrace geoengineering approaches to reversing it. This is because they believe that the ‘hand of man’ is implicated in most of our environmental problems and they see geoengineering as more of the same. Others, who are interested in exploring or developing geoengineering possibilities, are disinclined to believe that climate is changing. On their view planetary

> systems are relatively insensitive to human behaviour and for that reason we shouldn't worry too much about the risks of geoengineering. So to simplify: some people believe that there is a problem but that geoengineering is no solution; others believe that geoengineering is a solution but that there is no problem' (Jamieson 1996, 323).

This quotation is one of the many that emphasise the ambiguity and lack of correspondence between the various grey shades of geoengineering positions and the common black/white division between climate 'alarmists' and climate 'sceptics', which reinforces the importance of looking at geoengineering holistically.

Such a look is particularly relevant in examining the discourses about the potential misuses of geoengineering technologies, which should be considered in the broader context of the history of weather and climate modification, where many of the attempts to advance these technologies did not have peaceful intentions (Keith 2000, Fleming 2006, 2007, 2010, Bonnheim 2010)[7]. In fact, the narratives about the risk of hostile uses of geoengineering technologies should be seen not only in the context of climate modification history, but also in the context of other potential harmful technologies:

> 'It may be possible to reduce the risk of intentional misuse through governance arrangements such as those that have been used to control nuclear, biological and chemical weapons. Similarly, it may be possible to prevent risks from unintentional misuse through sound regulation. However, in some cases the only effective measures for reducing risk may also forestall beneficial uses of geoengineering, for example by having a general chilling effect on scientific progress in this area' (Powell et al. 2010, 2).

Concluding Remarks: Furthering the 'Democratisation and De-alienation' of the Geoengineering Debate

Using the internet as a primary source of information, we started our investigation by collecting different kinds of materials, including scientific articles, books, policy reports, films, interviews, media news and blog comments. We then analysed them to identify the main debates around geoengineering technologies.

Through this analysis we have identified three interconnected areas of current debate on geoengineering: geoengineering research and experimentation; geoengineering regulations and governance; and geoengineering implementation and misuse (Figure 1). Within these areas we have also identified the main arguments called into question in the geoengineering debates and the underlying 'master narratives' in which they are embedded (Figure 2).

The significance of geoengineering proposals can only be grasped in the context of the wider 'imaginary' of science and technology in which geoengineering narratives are rooted. Hence, we suggest examining those debates further, taking into consideration the dominant narratives of science, technology and society.

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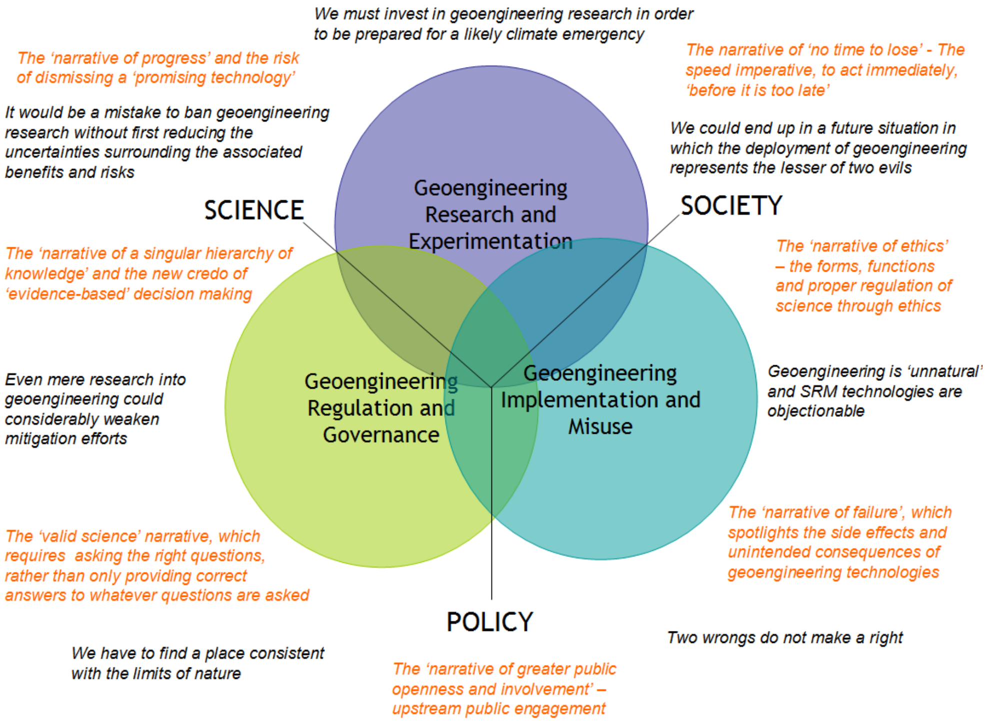
[7] Leading to the ratification of the UN Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques (ENMOD) in 1978.



We must invest in geoengineering research in order to be prepared for a likely climate emergency

The 'narrative of progress' and the risk of dismissing a 'promising technology'

It would be a mistake to ban geoengineering research without first reducing the uncertainties surrounding the associated benefits and risks

The 'narrative of a singular hierarchy of knowledge' and the new credo of 'evidence-based' decision making

Even mere research into geoengineering could considerably weaken mitigation efforts

The 'valid science' narrative, which requires asking the right questions, rather than only providing correct answers to whatever questions are asked

We have to find a place consistent with the limits of nature

The 'narrative of greater public openness and involvement' – upstream public engagement

The narrative of 'no time to lose' - The speed imperative, to act immediately, 'before it is too late'

We could end up in a future situation in which the deployment of geoengineering represents the lesser of two evils

The 'narrative of ethics' – the forms, functions and proper regulation of science through ethics

Geoengineering is 'unnatural' and SRM technologies are objectionable

The 'narrative of failure', which spotlights the side effects and unintended consequences of geoengineering technologies

Two wrongs do not make a right

Figure 2 – The three interconnected domains in which geoengineering debates are taking place: main arguments and underlying master narratives.

Different conceptions, understandings and value assumptions concerning the changing relationships between science and society, science and technology, and science and nature tend to shape the geoengineering debate and inform the analytical framework within which the geoengineering domain has been problematised (Scholte, Vasileiadou, and Petersen 2013, Sikka 2012, Huttunen and Hildén 2013, Luokkanen, Huttunen, and Hildén 2013, Nerlich and Jaspal 2012). This reinforces the need to unbind geoengineering discourses from the deeply embedded narratives of science, technology and society that present technoscientific innovation as the solution to our most critical problems and as a substitute for social change. Similarly, the construction of narratives that give meaning to human action within nature, and provide guidance for humans' domination of nature, deserves a more critical and open reflection than has been the case to date. As a result, many authors have been highlighting how important it is to consider public perceptions of geoengineering and therefore to help reveal the perceived moral orders underlying geoengineering proposals (Boyd 2008, Bracmort and Lattanzio 2013, Cicerone 2006, Miller 2010b, The Royal Society 2009).

The need for democratic decision-making and public engagement in the area of geoengineering has been clear for some time now (Jamieson 1996). However, only recently have the practical implications and challenges of such demands begun to be properly considered (Morton 2007, Miller 2010a, b, Powell et al. 2010, Bracmort and Lattanzio 2013, ETC Group 2010, NERC 2010a, Orr et al. 2011, CSPO 2010, Debatepedia 2009, Parkhill and Pidgeon 2011, Macnaghten and Owen 2011, Corner, Pidgeon, and Parkhill 2012, Poumadère, Bertoldo, and Samadi 2011).

In the context of current 'policy vacuums', characterised by 'a growing sense of urgency coupled with a lack of knowledge of what to do and a lack of institutions where the issues could be addressed' (Rommetveit, Funtowicz, and Strand 2010), these initiatives assume critical importance. And though the scope, scale and complexity of the climate change issues tend to 'render the fulfilment of the deliberative ideal a practical impossibility' (*Idem*), the recurrent claims that argue for a closer connection between science and society, with the purpose of exposing to public scrutiny the hidden assumptions, values and visions that are deeply embedded in geoengineering proposals, seem more than justified.

Therefore, in supporting the need to subject the scientific debate on geoengineering to more open and critical reflection, we highlight the importance of rebuilding the 'geoengineering scientific worldview' on social processes of trust and credibility (Irwin and Wynne 1996), in this way impelling climate change science to better reveal the competing interests, values and assumptions of climate engineering proposals. We also see this as an opportunity to promote critical thinking about social problems that tend to be 'circumvented' and reduced to technological fixes (Weinberg 1991), thus 'alienating' and 'diverting' our attention from an essential question, that of our place in nature.

In fact, the debates on climate engineering seem to offer an excellent framework within which to examine how modern science's 'alienation from the earth' is leading to the 'alienation from the world' (Arendt 1958), a condition clearly depicted by Funtowicz and Strand:

> 'Barring and bracketing the environmentalist talk – which also has been an important part of our own talk – of planetary dangers, we would like to propose that the planet is indeed not the object at risk. The object at risk is we ourselves as a collective (present and future) subjectivity and agency: the human right behind the human rights: that of personhood and hope. With personhood and hope in focus, the challenge is not the usual of what to do but, more importantly, how to do it as certain avenues of action are now deemed unacceptable' (Funtowicz and Strand 2011, 8).

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* The views expressed in this paper are those of the authors and do not necessarily represent the official views of the European Commission.

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Paula Curvelo

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Exploring the Ethics of Geoengineering through Images

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Abstract: Since the beginning of this century, the purpose and extent of intentional climate change proposals seem to have surpassed its original concepts and been appropriated by the various competing interests that inform the climate change debate. Indeed, many of the problems and uncertainties that geoengineering schemes evoke are feeding environmental controversies, while discourses become more and more politicized. In this context, the study of geoengineering narratives not only helps to unveil the ethical issues surrounding climate engineering experimentation, regulation and deployment, but also suggests an alternative way of looking at the climate change issue and the 'scalar dislocations' that it introduces into modern systems of experience and understanding [1]. Assuming that geoengineering is an illustrative metaphor of a particular kind of technoscientific promises and "technological fix" narratives that are emerging in our society, this paper seeks to analyse the value disputes hidden in geoengineering debates by adopting expanded notions of narrative, which account for the particular ways of rendering the world in both visual and verbal forms. It is hoped that this paper will contribute to an understanding of the potential of visual narrative research, while also considering the ethical issues in scientific and technological developments. In particular, it tries to suggest possible ways of exploring the meaning-making practices of production (encoding) and interpretation (decoding) of geoengineering images in order to analyse the contributions that visual methodologies can provide to enable us to understand the nature and causes of scientific and technological developments, the benefits and the risks, the perils and the promises of recent advances in science and technology and, last but not the least, the limits of rational analytical methods when it comes to characterizing complex problems.

Keywords: Narrative Theory, Visual Research Analysis, Geoengineering, Imag[in]ing, Ethics

From Geoengineering Narratives to Geoengineering Images

GEOENGINEERING IS THE deliberate large-scale intervention in the Earth's climate system, in order to moderate global warming. So far, most of the geoengineering technologies that have been explored fall into two main categories [2, p. ii, 3, 4]:

- Carbon Dioxide Removal (CDR) methods, which aim to reduce levels of carbon dioxide in the atmosphere by creating new carbon sinks or by enhancing the existing land or ocean carbon sinks.
- Solar Radiation Management (SRM) methods, which aim to reduce incoming solar radiation, by deflecting sunlight or by increasing the reflectivity of the atmosphere, clouds or the Earth's surface.

In recent years, the role of climate geoengineering technologies within the "*portfolio of response options to anthropogenic climate change*" has been the subject of increased discussion

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[5]. This new interest in the deliberate large-scale manipulation of the planetary environment is largely due to the 'grossly unsuccessful' attempts to lower the emissions of greenhouse gases [6] and to the urgency appeal that consider alternative strategies to current climate change mitigation efforts.

However, this so called 'plan B' is inevitably conditioned by the limited understanding of the scientific basis of the climate science and by major uncertainties regarding the impacts of these technologies on human and natural systems. Therefore, and in spite the conflicting arguments that prevail in the debates surrounding geoengineering technologies, there is widespread agreement on the need to consider the far-reaching ethical, political and social questions that intentional climate change proposals entail.

And although some attempts have been made to address this need (and to further ethical awareness amongst the scientific community), the development of an ethical framework that could inform policy responses to geoengineering research, deployment and governance is still missing.

In this sense, the overall objective of our research (which necessarily goes beyond the limits and scope of this paper) is to address the need to develop an analytical framework that can contribute to understanding the social, ethical and equity issues raised by geoengineering proposals, i.e. one that can be used as the basis for further analysis into the development and implementation of appropriate governance mechanisms to steer both geoengineering research and deployment.

Because the debates that are taking place at the interface between science and society tend to reveal the deeply held value assumptions that sustain geoengineering visions, as well as the underlying principles that shape geoengineering problematization, we felt that one possible way to fill the above mentioned gap was to explore the potential value of discourse analysis and narrative inquiry as a way to broaden our understanding of the ethical, political and social issues that geoengineering proposals raise.

Using the Internet as a major source of information, in a first stage of our investigation we made a collection of different kinds of materials (scientific articles, books, political reports, films, interviews, media news, comments on the blogosphere, etc.), which was subsequently analysed in order to identify the main debates around climate geoengineering technologies. Through that analysis we have identified three inter-connected areas within which current debates on geoengineering are taking place: Geoengineering Research and Experimentation; Geoengineering Regulations and Governance; and Geoengineering Implementation and Dual Use. Within these areas we have also identified the main disputed arguments (and values?) in the geoengineering debates, as well as the underlying master narratives in which they are embedded (Fig. 1)

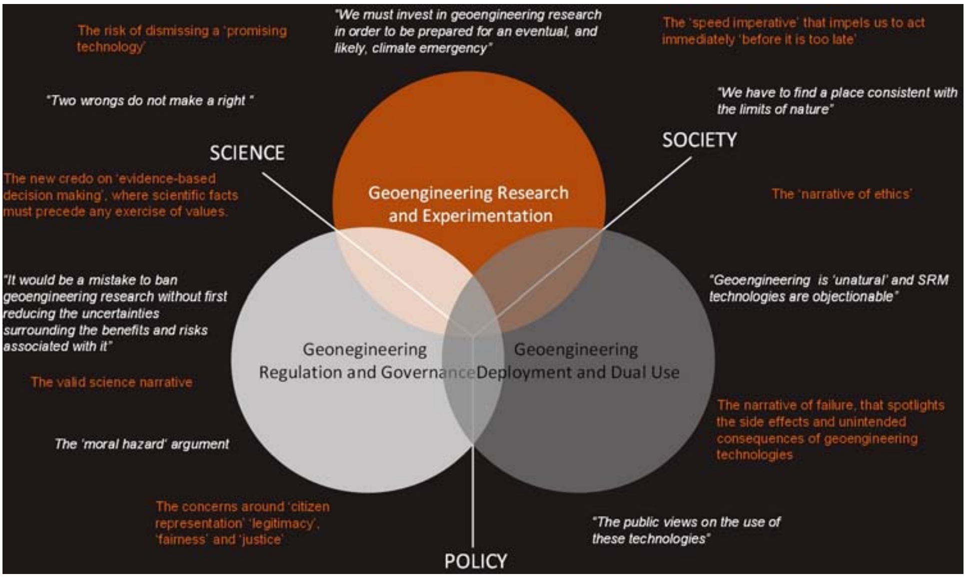

Fig. 1: The Three Interconnected areas within which Geoengineering Debates are taking Place-main Arguments and Underlying Master Narratives

However, while analysing the material collected during this first stage, we came across a wide range of images which we were unable to consider properly within the documentary analysis that we have been conducting. At first glance, some of these images seem to visually translate the textual content that surrounds them and do not reveal any other additional meanings to the discourses being analysed. Nevertheless, a significant number of images seem not only to complement some of the ideas expressed in textual terms, but also to add new and, somehow unexpected, meanings to these debates, thereby suggesting that there are other analytical dimensions to our investigation.

In this way the results of the first stage of our investigation constitute the starting point of a discussion that endeavours to understand the potential of visual narrative research, while considering the ethical, political and social issues present in the early stages of scientific and technological developments.

The rationale for following a narrative approach stems from three different but overlapping fields: Narrative theory; Visual Communication; and Visual Representation of Science. The literature on these fields provides the background for the discussion set out in the next section.

From Geoengineering Images to Geoengineering Narratives

The universe of Geoengineering abounds with images. From figures that attempt to represent the main characteristics of the two categories of geoengineering methods (Fig. 2), to illustrations that evoke human expectations, fears and fantasies about the control of nature (Fig. 3), and from attempts that seek to warn against the risks of a "geoengineered world", (Fig. 4), to images that endeavour to compare and rank major climate engineering proposals (Fig. 5) or claims that emphasize public involvement in discussion and decision-making in geoengineering research and governance (Fig. 6), this universe seems not only to fill, but actually to go far beyond the *visual science continuum* which has, at one extreme, the set of figures that convey data and, at the other, scientific illustrations, i.e. “*representations of how something might or could be*” [7].

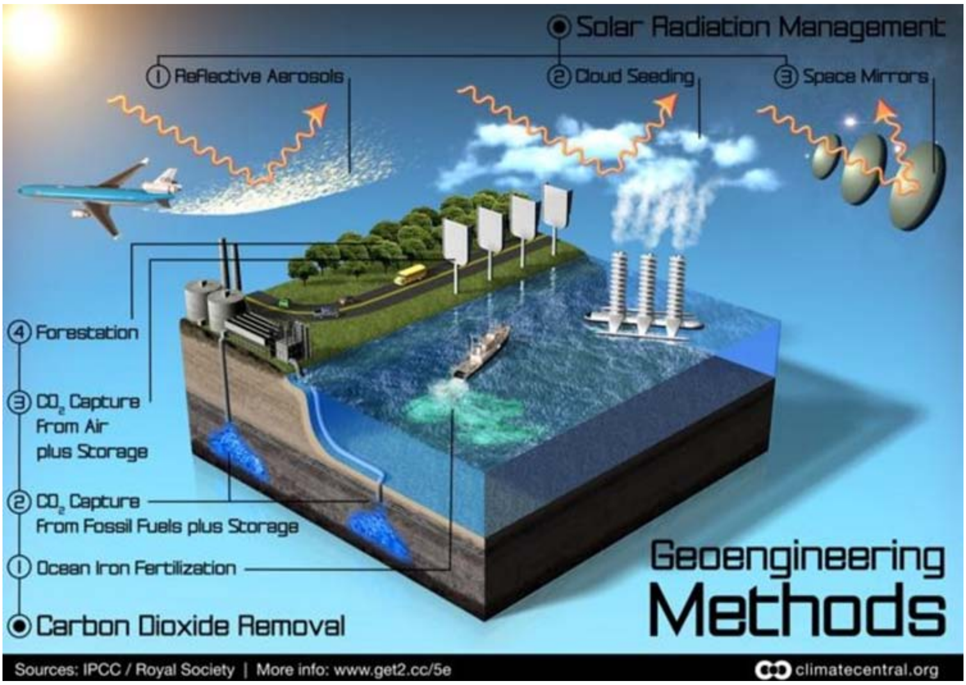

Fig. 2: Geoengineering Methods. From Climate Central (Nov 5th, 2010): *Geoengineering Methods*. Retrieved 02.08.2011, from http://www.climatecentral.org/gallery/graphics/geoengineering_schemes/. Reprinted with kind permission of Climate Central

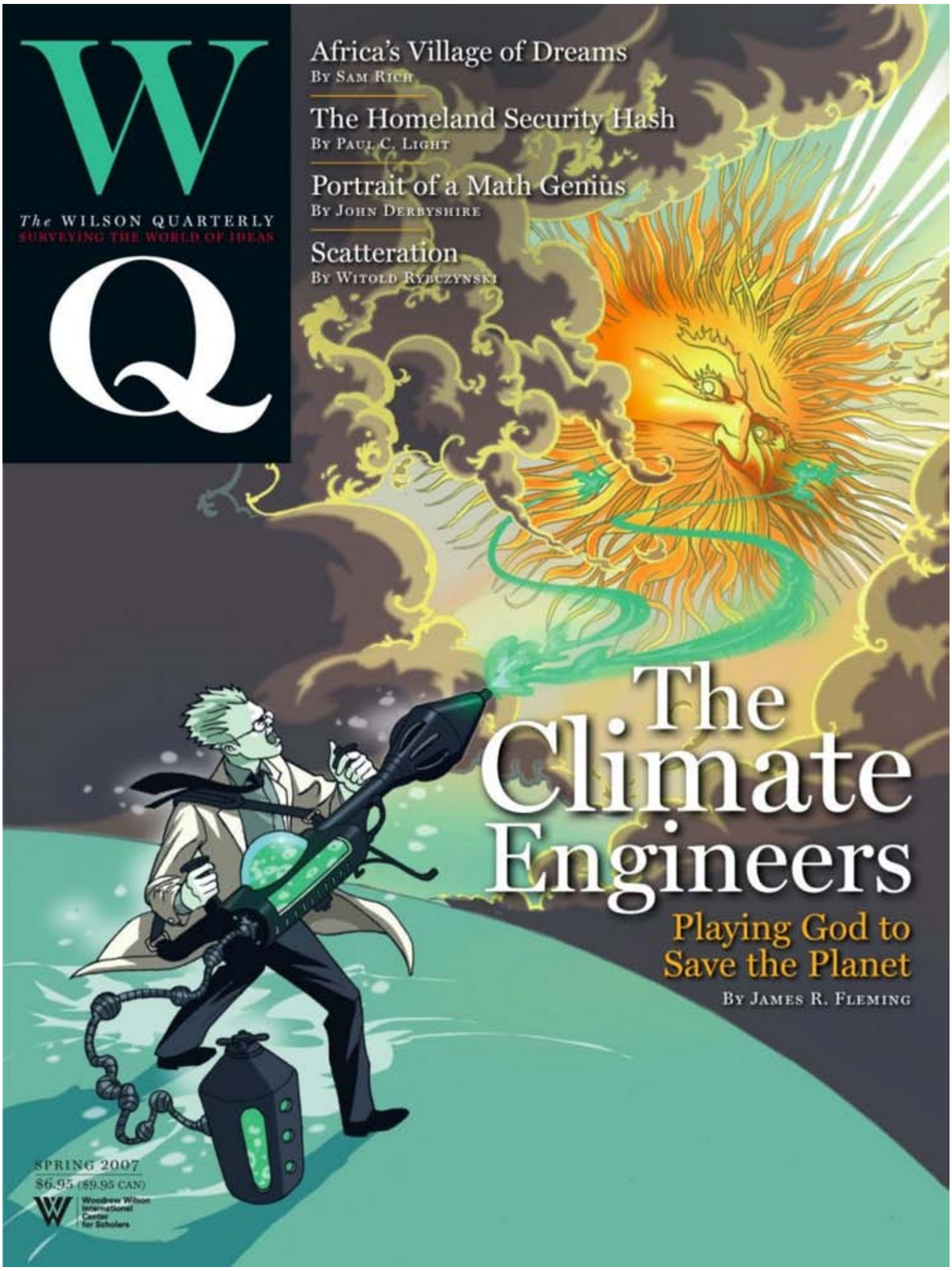

Fig. 3: The Climate Engineers. Front Cover from *The Wilson Quarterly*, Spring 2007. Reprinted with kind permission of *The Wilson Quarterly*

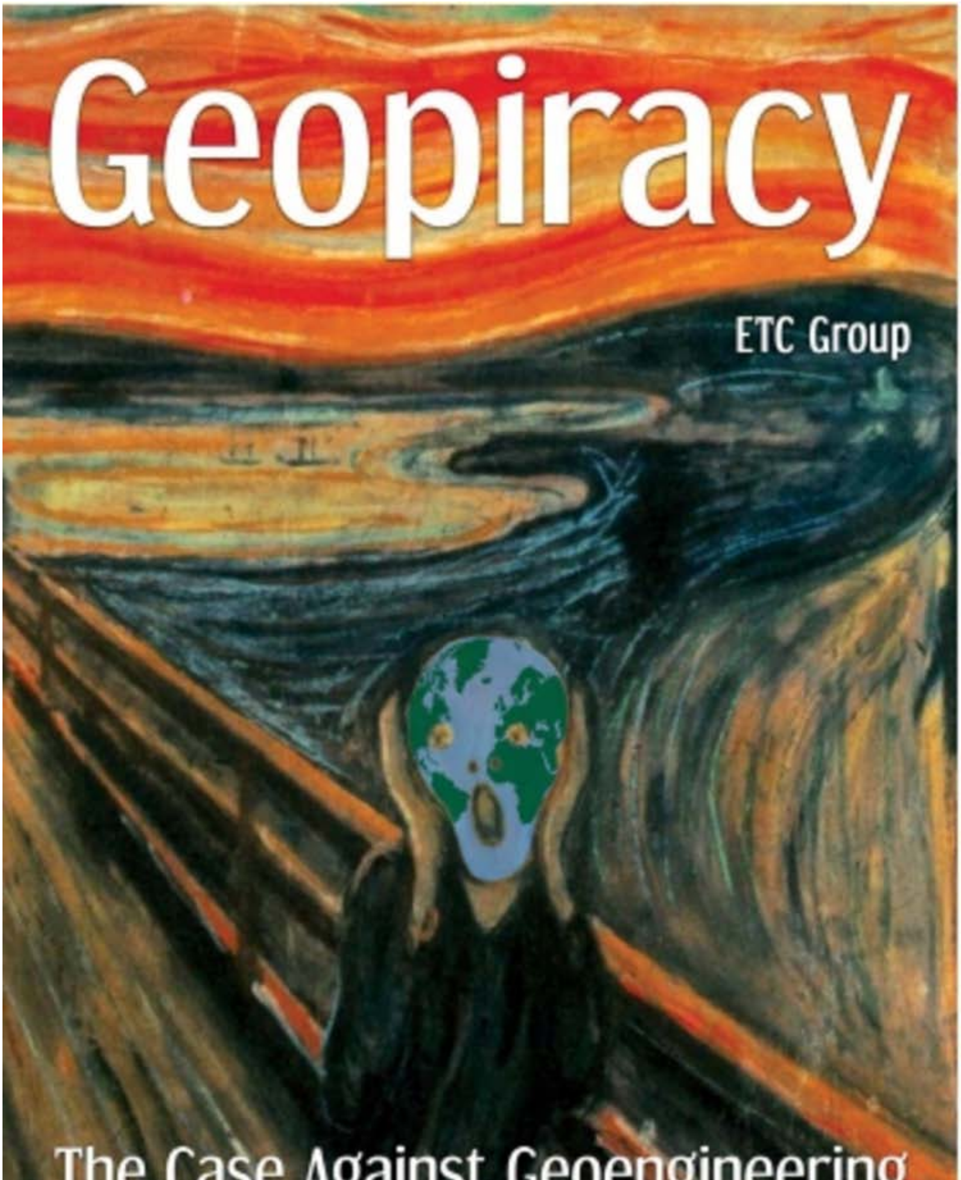

Fig. 4: The Front Cover of the ETC Group's Report *Geopiracy*, *The Case against Geoengineering* (*2010*). Design by Stig (www.shtig.net). Reprinted with kind permission of ETC Group

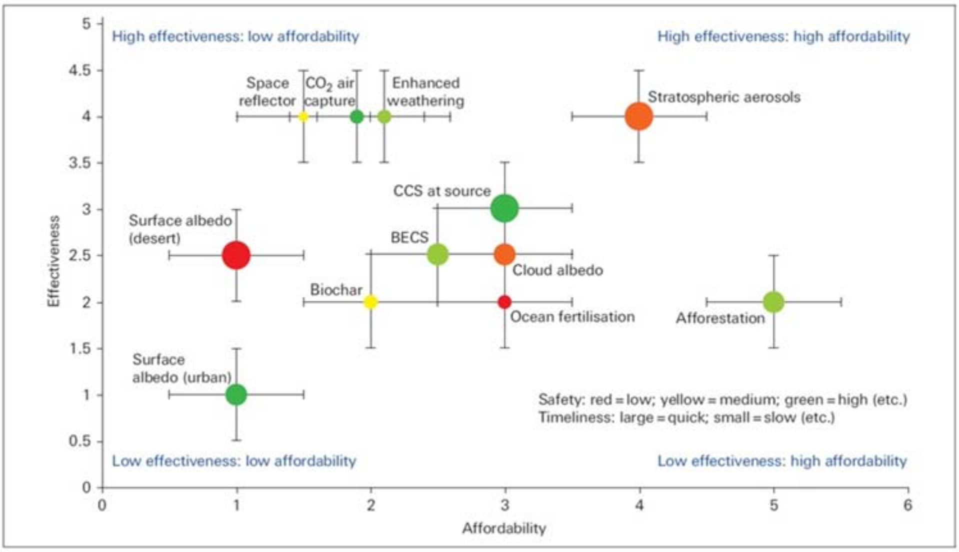

Fig. 5: A Preliminary overall Evaluation of the Geoengineering Techniques Considered in Chapters 2 and 3 of the Royal Society's Report (p. 49). From The Royal Society, Geoengineering the Climate: Science, Governance and Uncertainty, 2009, The Royal Society: London. pp. 98. Reprinted with kind permission of The Royal Society, London

Fig. 6: Hands Off Mother Earth (H.O.M.E). From ETC Group, *H.O.M.E.* Retrieved 02.08.2011, from http://www.handsoffmotherearth.org/. Design by Stig (www.shtig.net). Reprinted with kind permission of ETC Group

By assuming that pictorial expressions are not qualitatively different from verbal expressions [8, p. 330], we situate this *visual science continuum* in an expanded notion of narrative, which includes not only verbal forms, but also all other symbolic forms of expression.

Consequently, these images are now seen as part of the geoengineering story, by revealing facts, knowledge, values, fears, desires, promises, anxieties and incredulity, not only about the proposals for tackling climate change, but also and above all, by revealing what we know about the world and how we make sense of our place in it. In this context, in which climate geoengineering is seen as an illustrative metaphor of a particular kind of technoscientific promises and 'technofix' narratives that are emerging in our society, we underline the relevance of considering these images as narrative manifestations which reveal "how we think, what we value, and why we act" [8]. By suggesting that geoengineering images should be seen as visual narratives, i.e. as particular "ways of structuring thoughts" in order to make sense of the world, we draw on Walter Fisher's notion of the *Homo narrans* in the context of *the narrative paradigm*:

> '*The idea of human beings as storytellers posits the generic form of all symbol composition. It holds that symbols are created and communicated ultimately as stories meant to give order to human experience and to induce others to dwell in them in order to establish ways of living in common, in intellectual and spiritual communities in which there is confirmation for the story that constitutes one's life*' [*9, p. 63*]

Within the framework of this "narrative paradigm", we argue that both the *descriptive* and *explanatory* dimensions of geoengineering visual narratives need to be explored in order to broaden our understanding of the ethical, political and social issues raised by climate engineering proposals. These two dimensions of narrative research point towards the two different types of investigation mentioned by Polkinghorne [10, p. 161]: the first kind of narrative investigation aims "*to render the narrative accounts already in place which are used by individuals or groups as their means for ordering and making temporal events meaningful*"; the second kind of narrative investigation aims "*to construct a narrative account explaining* '*why*' *a situation or event involving human actions has happened*". Considering these two roles of narrative research, we sustain that a descriptive narrative investigation, in which we include the visual representations of geoengineering, may help us to articulate the various (conflicting?) narrative schemes that operate in the interfaces between science, policy and society, and which are taking place not only in the realm of rationality, knowledge, and facts, but also in the realm of subjectivity, values, intentions, imagination and fiction.

However, it is only within an explanatory narrative approach that we will be able to address the imperative ethical issues regarding the causes, motivations and assumptions that conspired towards the emergence of the idea of a "geoengineered world", in an attempt to "*to trace back modern world alienation, its twofold flight from the earth into the universe and from the world into the self, to its origins, in order to arrive at an understanding of the nature of society as it had developed and presented itself at the very moment when it was overcome by the advent of a new and yet unknown age*" [11, p. 6]. Because explanatory narrative research is retrospective and retrodictive[1], the adoption of this kind of approach does not seem an easy task whilst considering the ongoing debates on geoengineering. Notwithstanding,

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[1] "(…) in that: a) certain events in the past are interpreted as hanging together by being narrated into a story with a beginning, middle, and end; and b) a story must be ended before it can be explained". Sandelowski, M., Telling Stories: Narrative Approaches in Qualitative Research. *Image: Journal of Nursing Scholarship*, 1991. 23(3): p. 161–166.

we believe that an analogy can be made with other stories that have already ended, making this task not only possible, but also an imperative:

> *I can only answer the question* '*What am I to do?*' *if I can answer the prior question* '*Of what story or stories do I find myself a part?*' *We enter human society, that is, with one or more imputed characters-roles into which we have been drafted-and we have to learn what they are in order to be able to understand how others respond to us and how our responses to them are apt to be construed* [12, p. 216].

In addition, we must confront the resistance offered by science to this kind of investigation. In fact, explanatory narrative research is not typically used in the sciences, partly because "*narrative truth is distinguished from other kinds of formal science truths by its emphasis on the life-like*, *intelligible and plausible story. Stories typically reflect a coherence (as opposed to correspondence) theory of truth in that the narrator strives for narrative probability – a story that makes sense; narrative fidelity – a story consistent with past experiences or other stories: and aesthetic finality – a story with satisfactory closure and representation appeal*" [13, pp. 164–165].

In the context of this discussion, which points to some of the presuppositions that underpin W. Fisher's narrative paradigm [14, pp. 64–65], it is important to reinforce the difference between the elements of a narrative theory, a theoretical distinction that was stressed by structuralists, who considered that each narrative has two parts: a story (the *what* in a narrative that is depicted) and the discourse (the *how*). According to Chatman [15, pp. 19–22], the story consists of the content or chain of events and the existents (characters and items of setting), while the discourse refers to the means by which the content is communicated, thus comprising two subcomponents: the structure of narrative transmission and its manifestation. In order to capture all elements of the communicative situation, Chatman reminds us that narrative is a semiotic structure, which presupposes that it should include a form and a substance of expression and a form and a substance of content (Fig. 7).

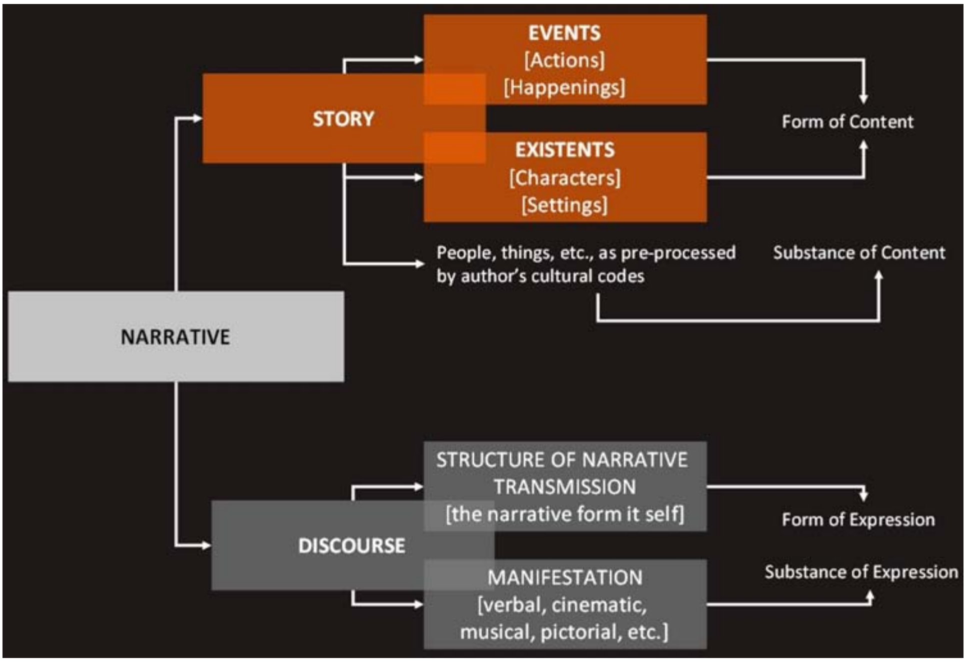


Fig. 7: Elements of a Narrative Theory (Adapted from Chatman, 1978, p. 26).

These considerations forwarded by Barbatsis provide the theoretical basis to understand the difference between the meaning–making role of an image's pictorial content and its pictorial form or syntax (Fig 8):

> "*In a visual discourse, then, the notion of author is recast as imager and the notion of reader is recast as viewer. In this same mode, the textual properties that inscribe a visual point of view are recast as implied imager and implied viewer. Finally, the textual properties that inscribe a sense of being told something are recast in terms of being shown something, which can be thought of as the showing presence or "show-er" and "show-ee" positions of a visually composed discourse. The terms of a visual narrative syntax can be identified, then, as the inscription of a pictorial point of view (implied imager) along with a pictorial vantage point from which to view the imaged storyworld (implied viewer) as well as the organization of picturing elements (show-er) with an implication of the way this organization is meant to be seen (show-ee)* [8, p. 341].

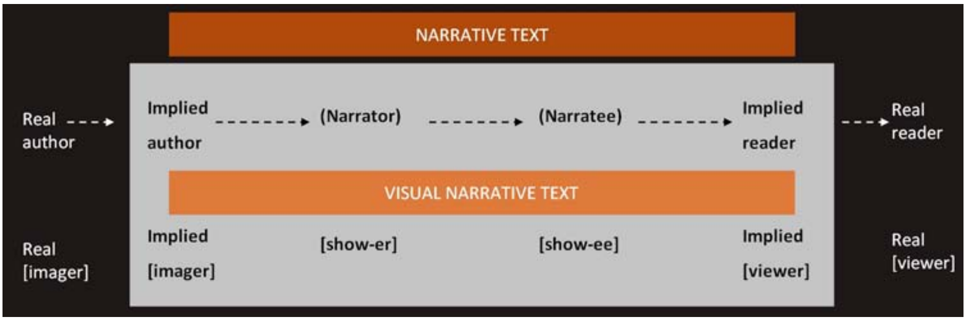


Fig. 8: Narrative Communication Structure (Adapted from Barbatsis, 2005, p. 339)

Besides the abovementioned distinction, which allows us to understand how a narrative discourse mode may be recognized in the formal features of an image, there are other available theoretical frameworks which should be taken into account when assessing visual representational practices in knowledge building and science communication. In this context, we make a final reference to the conceptual framework proposed by Pauwels for the analysis of visual representations in science [16]. This framework takes into consideration the "*diversity that exists with regard to types of translation processes and actors in the production cycle, as well as the different purposes and intents of representations and specific contexts of use*" [Idem, p. 4], in order to address the complex process of meaning-making that has an "*impact on what can be known and how*, *on what is revealed or obscured*, *and on what is included or excluded*" [Idem, p. 5]. Moreover, the broad amplitude of intended or unintended choices that may influence visual representation is a fundamental aspect to which a visual analyst should be alert. This broad amplitude of the representational space, in what Pauwels refers to as the "visual representational latitude", is determined by the nature of the problem being depicted (type of referent), by the intentional and unintentional choices of the author (the context of production), and also by the characteristics of the audience in relation to a particular visual representation (the context of use) – Fig. 9.

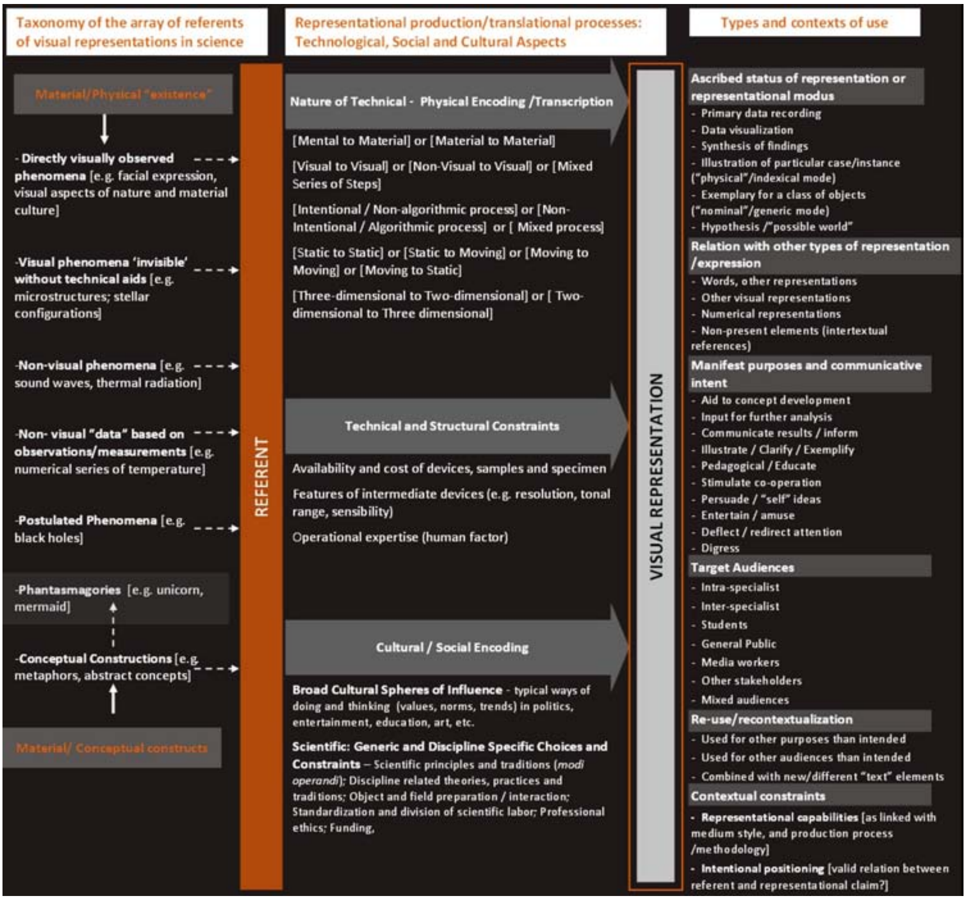


Fig. 9: A Conceptual Framework for Analysing and Producing Visual Representations in Science (Adapted from Pauwels, 2006, p. 23)

Two Exercises on the Visual World of Geoengineering – Exploring the Potential of Visual Research Analysis

Taking these theoretical considerations into account, we will now focus our attention on two different geoengineering images with a view to exploring the opportunity and the potential of a visual narrative approach in the context of our investigation.

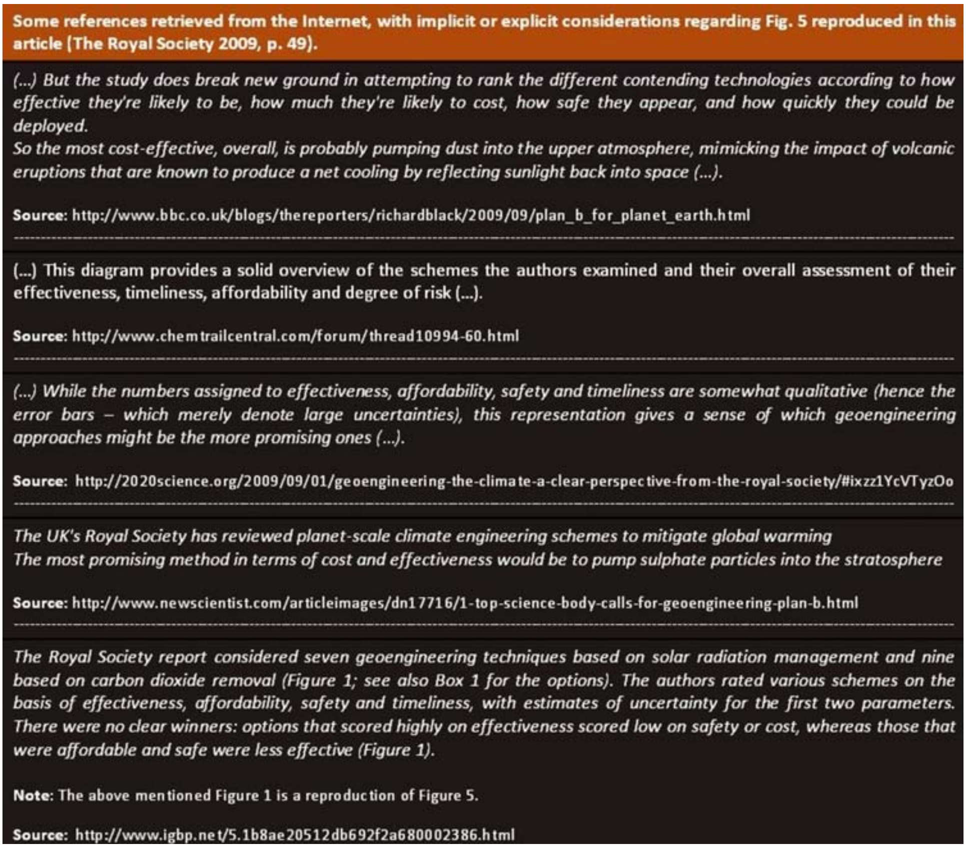
The Visual Representation of Science and the Act of Communication

One of the first images that drew our attention for possible new dimensions of analysis was included in the report issued in September 2009 by the UK Royal Society, the aim of which was "*to provide an authoritative and balanced assessment of the main geoengineering options*" [2]-Fig. 5.

The [con]text where this figure appeared is very explicit about its purpose and about the uncertainties that surround different geoengineering methods: this figure was meant to provide a provisional overall evaluation based on different methods discussed in the Royal Society's report, that "*should be treated as no more than a preliminary and some what illustrative attempt at visualizing the results of the sort of multi-criterion evaluation that is needed*" [2, p. 49] and "*It may serve as a prototype for future analyses when more and better information becomes available*" [*Idem Ibidem*]. As explained in the text "*indicative error bars have been added to avoid any suggestion that the size of the symbols reflects their precision-but note that the error bars are not really as large as they should be, just to avoid confusing the diagram*)" [*Idem Ibidem*].

From the perspective of the reception theory, this textual explanation not only provides the elements necessary to clarify the point of view of the author-imager, thereby guiding the reader-viewer in the process of meaning-making, but also reveals the author-imager's concerns in terms of narrative probability (coherence) and narrative fidelity (truthfulness).

Despite the efforts to clarify its "*functional adequacy*", i.e. the limits of its potential uses in acts of communication and "*the correct type of intentional relationship to its subject matter*" [17, p. 220], the narrative structure of this image and the contexts in which it has been reproduced and analysed tend to underestimate the uncertainty that surrounded its production and the precautions regarding its uses, thereby stretching its original purpose and meaning, leading to a range of different considerations as to the most promising geoengineering technologies and conclusions of this report (Fig. 10).


Some references retrieved from the Internet, with implicit or explicit considerations regarding Fig. 5 reproduced in this article (The Royal Society 2009, p. 49).

(...) But the study does break new ground in attempting to rank the different contending technologies according to how effective they're likely to be, how much they're likely to cost, how safe they appear, and how quickly they could be deployed.
So the most cost-effective, overall, is probably pumping dust into the upper atmosphere, mimicking the impact of volcanic eruptions that are known to produce a net cooling by reflecting sunlight back into space (...).

Source: http://www.bbc.co.uk/blogs/thereporters/richardblack/2009/09/plan_b_for_planet_earth.html

(...) This diagram provides a solid overview of the schemes the authors examined and their overall assessment of their effectiveness, timeliness, affordability and degree of risk (...).

Source: http://www.chemtrailcentral.com/forum/thread10994-60.html

(...) While the numbers assigned to effectiveness, affordability, safety and timeliness are somewhat qualitative (hence the error bars – which merely denote large uncertainties), this representation gives a sense of which geoengineering approaches might be the more promising ones (...).

Source: http://2020science.org/2009/09/01/geoengineering-the-climate-a-clear-perspective-from-the-royal-society/#ixzz1YcVTyzOo

The UK's Royal Society has reviewed planet-scale climate engineering schemes to mitigate global warming
The most promising method in terms of cost and effectiveness would be to pump sulphate particles into the stratosphere

Source: http://www.newscientist.com/articleimages/dn17716/1-top-science-body-calls-for-geoengineering-plan-b.html

The Royal Society report considered seven geoengineering techniques based on solar radiation management and nine based on carbon dioxide removal (Figure 1; see also Box 1 for the options). The authors rated various schemes on the basis of effectiveness, affordability, safety and timeliness, with estimates of uncertainty for the first two parameters. There were no clear winners: options that scored highly on effectiveness scored low on safety or cost, whereas those that were affordable and safe were less effective (Figure 1).

Note: The above mentioned Figure 1 is a reproduction of Figure 5.

Source: http://www.igbp.net/5.1b8ae20512db692f2a680002386.html

Fig. 10: References retrieved from the Internet (Sep. 2011) related with figure 5 of this article-included in the Royal Society's Report (2009, p. 49)

The contexts in which this image is used point to the complex meaning–making role of an image's pictorial content and its pictorial form or syntax. Furthermore, they also highlight the ever-growing circulation of information worldwide (mainly on the Internet) and how easy it is to distribute, copy, transform and recombine images, thus facilitating a rapid appropriation (or misappropriation), sometimes for uses that were not originally intended. This situation not only denatures the established rules of graphic communication, but also disrupts the familiar practices of image production and exchange [*Idem Ibidem*].

In this case, a figure that was conceived as a starting point for a research that is still required runs the risk of being seen as a culminating point of a research already done. In fact, this single figure and the discourses that surround it seem to offer a wealth of opportunities for reflection, not only about geoengineering science, but also about:

- the intertextuality associated with this type of representation;
- the roles that these kinds of images play in the process of knowledge production;
- the need to open up the process of scientific research to wider scrutiny;
- the challenges related to the visual representation of uncertainty;

- the dissemination of knowledge, and the communication of science among professionals and to the public;
- the need to tackle the dilemmas of the Science-Policy interface, i.e. the difficulty of accommodating the "*growing expectations for science*" [18], which has to simultaneously address issues of policy relevance, scientific quality and legitimacy, in a context where "*facts are uncertain*, *values in dispute*, *stakes high and decisions urgent*" [19, p. 1882].

In fact, this attempt to represent and visualize "systems uncertainties" [Idem] with the traditional 'language of science' seems to tie itself into a profound paradox: how can we address what is not fully known in a scientific problem with the same (and expected?) quantitative scientific tools and concepts that are used to communicate what is known? Science is for definition related with knowledge and with what can be logically and rationally explained. In this attempt to understand "systems uncertainties", to explain the inexactness of scientific knowledge, and to communicate the limits of what can be known, science has primarily been using numerical language, the language of objectivity, namely what we have been educated to think of as a 'language of precision':

> *A political demand for scientific consensus and unambiguous quantitative information in the assessment process would be likely to grow as science moves nearer to the context of policy making and the political process surrounding the climate negotiations* [20, p. 59].

The risk is clear: we may have been led to overestimate what we know about uncertainty, and to underestimate the inexactness, unreliability, and -most of all-the ignorance of it.

This paradox, linked with the imperative of precision in the field of scientific communication about 'systems uncertainties', is clearly seen in a recent article published in *Science* about the challenges of visualization and communication of uncertainties resulting both from incomplete or disputed knowledge and from indeterminacy about the future [21]. Although drawing attention to the emphasis that has been given to probability and risk assessment approaches, the authors question not only the uncertainties that those approaches may comprise ("What if we're uncertain about probabilities?"), but also the inadequacy of adopting such approaches in a context of 'post-normal science' [19, 22].

> *Many hazards facing society are subject to deeper uncertainties than are reflected in probabilities and measures of statistical error. Counterterrorism*, *climate change*, *pesticides*, *deep-sea drilling*, *and nuclear waste disposal are often characterized by fundamental disagreements*, *and even ignorance*, *about the likelihood and values of different consequences*, *as well as by essential indeterminacy about a future governed by human behaviour.*
>
> *People's understanding of these hazards depends on their beliefs about how the world works and how society should be ordered. Here a language of caution and humility is appropriate*, *and decisions are sought that are robust*, *resilient*, *and can adapt to possible future surprises [21*, *p. 1400].*

Thus, by assuming that "*real science depends for its progress on continual challenges to the current state of always-imperfect knowledge*" [23], it is essential to understand the role that visual representation of science can play in "*anchoring amid uncertainty*" [24] and in making sense of plausible interpretations, options, and scenarios imagined by experts.

Extending the Debate on Geoengineering – Expanding the Story, the Discourse and the Visual

The second image on which we will briefly focus our attention was published in the cover of the ETC Group's[2] report "*Geopiracy*, *The case Against Geoengineering*" (Fig. 4). As mentioned in this report "*the cover is an adaptation of the Scream by Edward Munch, painted in 1893* [3]*. Munch painted several versions of this image over the years, which reflected his feeling of 'a great unending scream piercing through nature'. One theory is that the red sky was inspired by the eruption of Krakatoa, a volcano that cooled the Earth by spewing sulphur into the sky, which blocked the sun. Geoengineers seek to artificially reproduce this process*" [26, p. i].

This image had been strategically used to strengthen the ETC Groups' position and to attract the lay public into desired positions: i) to institute a moratorium on all geoengineering activities outside the laboratory, and ii) to promote a real governance discussion on geoengineering, open to public scrutiny, with the full participation of civil society organizations, indigenous peoples and social movements, and guided by the precautionary principle, in due respect of existing international laws and free from corporate influence and private interests [*Idem*].

The power of this image relies on its compositional structure, in which a central figure exhibits the symptoms of fear described by Mentegazza and Mosso (pallor, open eyes, flared nostrils, screams, trembling, and the whole body oscillating like a pendulum) [27, p. 56] and on the structure of meaning relationships [28, p. 237] that have made this picture a symbol of the anxiety and neuroses in our own society, "*a great infinite scream passing through nature*" [27, p. 29].

This circumstance reinforces the need to consider the aspects of how and why an image might come to "stand for" something else. Focused on nanotechnology representations, Ruivenkamp and Rip mention that it is "*the entanglement between imaging and imagining which is the key to understanding what images do*" [29, p. 185]. While imaging refers to the creation of images based on data, aiming at resemblance and offering '*a view on what is out there*', imagining refers to the creation of impressions, offering visions of worlds that might be realized. To capture the *continuum* between imaging and imagining, the authors introduce

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[2] ETC Group is an international civil society organization that aims to address the global socioeconomic and ecological issues surrounding new technologies and is particularly concerned with their impact on indigenous peoples, rural communities and biodiversity

[3] According to Munch (2005) the inspiration for this image came from the following event: "*One evening I was walking out on a hilly path near Kristiania – with two comrades. It was a time when life had ripped my soul open. The sun was going down – had dipped in flames below the horizon. It was like a flaming sword of blood slicing through the concave heaven. The sky was like blood – sliced with strips of fire – the hills turned deep blue the fjord – cut in cold blue, yellow, and red colors – The exploding bloody red – on the path and hand railing – my friends turned glaring yellow white – I felt a great scream – and I heard, yes, a great scream – the colors in nature – broke the lines of nature – the lines and colors vibrated with motion – these oscillations of life brought not only my eye into oscillations, it brought also my ears into oscillations – so I actually heard a scream – I painted the picture Scream then*". 25. Munch, E., The Private Journals of Edvard Munch: We Are Flames Which Pour Out On the Earth. 1st ed, ed. J.G. Holland. 2005, Madison, Wisconsin: University of Wisconsin Press. 224.

the notion of 'imag(in)ing', which has to do with representation and its idea of 'standing for' and being able to 'act for', as in political representation.

Nanotechnology and geoengineering seem to have little in common in terms of each world's view. At first glance, the nanoscale invisibility clashes with the heavily emphasised (but also invisible) geoengineering global-scale expression. Nevertheless, and not considering the numerous linkages between nanoscale and global-scale processes[4], both technological worlds have been challenged by attempts to provide scientific reliable representations of possibilities. As in Nanotechnology, geoengineering images balance the past, present and the future in order to communicate the results of recent experiments and major achievements, as well as to present the potentialities, drawbacks and risks associated with these technologies. Indeed, and as is likely, given what is happening with nanotechnology (and other emerging technologies?), the visual representation of geoengineering also involves practices of 'entangling' present achievements and future visions of what it may become, drawing attention to the anachronism that tends to be associated with the innovation processes in the context of knowledge production. This anachronism reinforces the relevance of the 'idiom of co-production' [31] and the explanatory power it confers by thinking of natural and social orders as being produced together. In this perspective, the anachronism one may find in geoengineering imag(in)ing should be seen as a manifestation of the concept of co-production, taking into consideration that "*the ways in which we know and represent the world (both nature and society) are inseparable from the ways in which we choose to live in it*" [31, p. 2].

Final Remarks

It has been suggested for a while now that there is a need for deliberative governance and public engagement in the climate geoengineering field [32], although it is only recently that the practical implications and challenges of such demands began to be addressed [33–37]. In this context, many authors have been arguing about the importance of considering public perceptions of geoengineering, thus helping to further unveil the perceived moral orders underlying these proposals [2, 35, 37–39].

As we attempted to demonstrate in the previous section, the full meaning of geoengineering debates can only be perceived if it is connected with the larger social imaginary of science and technology in which geoengineering narratives are rooted. Hence, it is suggested that those narratives should be further interrogated by expanding its notion to include pictorial forms of expression, in order to consider alternative ethical paradigms, such as discursive or deliberative ethics [40, 41]. In doing so, we not only clear the path to more open and critical reflection, but also assume the importance of rebuilding the 'geoengineering scientific worldview' based on social processes of trust and credibility, in this way driving climate change science to reveal more clearly the competing social interests, values and assumptions [42].

In periods of uncertainty and change, where trust cannot be taken for granted and where important values of humanity are put under pressure by scientific and technological hubris [43], it is important to remember that "*Modern natural science owes its great triumphs to having looked upon and treated earth-bound nature from a truly universal viewpoint*, *that*

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[4] Which have been explored by different authors (cf. 30. Brussaard, C.P.D., *et al*., *Global-scale processes with a nanoscale drive: the role of marine viruses.* ISME J, 2008. 2(6): p. 575–578.

is, from an Archimedean standpoint taken, wilfully and explicitly, outside the earth" [11, p. 11]. Thus, we should also consider the potential of visual representations in science to usher in a responsible "second Copernican revolution", one that must be a reversal of the first, enabling us "*to look back on our planet to perceive one single*, *complex*, *dissipative*, *dynamic entity*, *far from thermodynamic equilibrium—the* '*Earth system*'" [44, p. C19].

As mentioned by Schellnhuber, this is an immense geo-cybernetic task that can be summed up in three fundamental questions: i) what kind of world do we have? ii) what kind of world do we want? iii) what must we do to get there? [*Idem*]. These three questions suggest the enormous cross-disciplinary challenges posed by social problems that tend to be 'circumvented' and reduced to technological fixes [45], therefore claiming for a research ethics that no longer can be dissociated from an environmental ethics if a 'scientific stable society' is to be achieved:

> «*Knowledge is power*, *but it is power for evil just as much as for good. It follows that*, *unless men increase in wisdom as much as in knowledge*, *increase of knowledge will be increase of sorrow*» [46, p. 1307].

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Questioning the Geoengineering Scientific Worldview

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Questioning the Geoengineering Scientific Worldview

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Abstract: Over the last few years, geoengineering, or the 'deliberate large-scale intervention in the Earth's climate system, in order to moderate global warming', has attracted increasing attention among strategies to limit the impact and consequences of climate change. However, the understanding of the physical science basis of geoengineering is still limited, and there are still major uncertainties concerning the impacts these technologies might have on human and natural systems. The self-assertive invasion of nature's various domains, the scale and complexity of the technoscientific tasks involved, the unpredictable long-term impacts of geoengineering actions, and the huge uncertainties that these proposals raise point to a shift in the nature of human action that requires a commensurate ethics of foresight and responsibility. If there is a decision to embark on such an ambitious project, a major effort should be made to scrutinise and gain a deeper understanding of the geoengineering scientific worldview. In fact, the full meaning of geoengineering proposals can only be grasped in the context of the larger social imaginary of science and technology in which geoengineering narratives are rooted. In this paper, two different contextual frameworks from which to address these issues are presented and analysed. The first represents the mainstream Earth System Science perspective, while the second corresponds to an alternative view from the field of social studies of science and technology. Central to both is the concept of an 'epochal break'. In the former, this is in terms of the Human-Earth relationship, in the latter, in terms of the relationship between science, technology and society. It is hoped that this approach may contribute to clearing the path towards more open and critical reflection about the competing interests, values and assumptions of climate engineering proposals.

Keywords: Geoengineering, Climate Engineering, Earth System Science, Anthropocene, Technoscience, Epochal Break

Why Geoengineering?

The term 'geoengineering' was coined in the 1970s by the physicist Cesare Marchetti to describe a proposal for tackling the problem of CO_2 control in the atmosphere with a CO_2 management system, 'where CO_2 is collected at proper fuel transformation points and finally injected into the deep seas taking advantage of natural thermohaline circulations' (Marchetti 1977, vi).

Almost at the same time, on the other side of the globe, the Russian climatologist Mikhail Budyko was probing the potential of different techniques to modify the aerosol layer of the stratosphere to prevent the warming of the climate (Schneider 1996; Bonnheim 2010; Budyko 1977). Some wider implications of these early findings were immediately recognised:

> The possibility of 'geo-engineering' – large-scale climatic modification as a strategy to offset an 'expected' major global climatic change – may not be that far off in the future. (…) However, the risks of these climatic control measures must be considered along with any possible benefits that might be derived. First, in the face of the present theoretical uncertainties, any specific operation to compensate for an 'expected' climatic effect could conceivably produce an over-response in the system. It is quite possible with today's rather crude estimates that the magnitude of the 'expected' climatic perturbation could be overestimated and the magnitude of the deliberate intervention could be underestimated. (…) if climatic deterioration were to follow climatic control operations, some nations could, in the absence of a definitive theory of climate, *perceive* that such climatic 'corrective' measures directly caused the deterioration. Thereby, these nations could demand restitution from the climate controllers, leading to a scenario in

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> which the political – and possibly military – implications might be difficult to foresee. (Schneider and Temkin 1978, 242-243)

From that moment on, the dice were cast. Not only had these discoveries opened up a new chapter in the history of climate change, but also the dominant features of the consequentialist worldview began to 'exhaust' and 'entrench' the ethical debate on geoengineering into a 'process of rational calculation' – a process that has been largely informed by the 'language of risk'[1] (Adam and Loon 2000), and for which 'the most ethical course is the best one determined by summing the value of the costs and benefits, perhaps weighted by risks, and maybe with some account of distributional effects' (Hamilton 2011).

Thus, with questions regarding the deeper meanings of geoengineering proposals already undermined by dominant utilitarian thinking, the risks mentioned by Schneider and Temkin have not diminished. In fact, they have expanded, as the 'possibility of geo-engineering' is becoming increasingly real.

Two Fundamental Questions

Since the adoption of the United Nations Framework Convention on Climate Change (UNFCCC), responses to address climate change have until recently fallen within two major groups of strategies (IPCC 2007):

I. mitigation measures, which comprise all human activities to reduce emissions or enhance the sinks of greenhouse gases such as carbon dioxide, methane and nitrous oxide, and
II. adaptation measures, which include any adjustments made to natural or human systems in response to actual or expected impacts of climate change, with the aim of moderating harm or exploiting beneficial opportunities.

Over the last few years, however, geoengineering, or the 'deliberate large-scale intervention in the Earth's climate system, in order to moderate global warming' (The Royal Society 2009, 1), has attracted increasing attention among strategies to limit the impact and consequences of climate change. Accordingly, in June 2011, the United Nations Intergovernmental Panel on Climate Change (IPCC) organised an expert meeting to discuss the latest scientific basis of geoengineering, its impacts and response options, and to identify key knowledge gaps that could be filled in the short and longer terms.

As stated in the meeting report, 'the understanding of the physical science basis of geoengineering is still limited and IPCC will, for the first time, assess this in several chapters of the WGI contribution to AR5. Improved scientific understanding of the impacts of geoengineering proposals on human and natural systems will be assessed by WGII. WGIII needs to take into account the possible impacts and side effects and their implications for mitigation cost in order to define *the role of geoengineering within the portfolio of response options to anthropogenic climate change*. Furthermore, this includes an evaluation by WGIII of options for appropriate governance mechanisms' (Edenhofer et al. 2012, 19, emphasis added).

Although the three IPCC Working Groups are expected to make a positive contribution to the current state of understanding of geoengineering in the Fifth Assessment Report (AR5), two fundamental questions are likely to be excluded from the scope of the AR5.

- The first question draws attention to the role geoengineering technologies play in ongoing climate change debates. Thus, in the light of the recent report of the IPCC Expert Meeting on Geoengineering, it could be formulated as follows: *Why is*

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[1] Whether by focusing on the risks of geoengineering technologies, or, in an almost paradoxical way, by assuming some of its specific methods as useful tools to manage climate risks (Moreno-Cruz and Keith 2012).

geoengineering becoming a part of the portfolio of response options to anthropogenic climate change?

- Having in mind the proper goal of technology use (Sandler 2009), the second question is: *How will geoengineering technologies improve the human condition now and in the long term?*

Though these are not typical of the scientific and technical questions facing the three IPCC Working Groups, it seems reasonable to consider that attempts to answer them would have had priority, or, in view of the risks perceived early on, would have taken place during the initial stages of geoengineering research.

The formulation of these questions is intended to highlight the need to unlock the geoengineering debate from the path-dependent questions that, almost invariably, provide justification for more and more research. Thus, it takes the standpoint that scientific enterprise is not merely a matter of epistemic permissibility, but also of moral permissibility. An enterprise that entails methodological choices of perspective − 'What is to be studied, by what means, for what purpose?' −, which cannot be excused from moral consideration and cannot be thought of as something entirely outside the realm of action (Strand 2002).

> We have to choose what we want to know, imposing a context; research per se often irreversibly changes the world through its invention of technology; and the course of this development is not inevitable, but has a historical character. (Strand 2002, 172)

Therefore, these fundamental questions demarcate themselves from the technically feasible and cost-effective responses that, within a utilitarian framework, have been advanced in geoengineering debates, suggesting that it is only within the development of a systematic discourse, involving ethics − as accompanying research ('Begleitforschung') (Hronszky 2005) − that the following far-reaching presuppositions which underpin our formulations can be considered:

- the need to gain a deeper understanding of the theoretical assumptions, motivations, and interests involved in the development of different geoengineering methods;
- the need to reflect on the goals and visions that shape geoengineering technologies;
- the necessity to explore and disentangle the imaginaries, commitments, and representations of nature and of the human being that inform geoengineering debates;
- the necessity to scrutinise the expectations, embedded values and ways of making sense of a *geoengineered world*.

Though some recent works have contributed to a better understanding of these issues, there is still a lack of critical thinking about how the broad set of geoengineering methods and technologies might 'contribute to human flourishing in socially just and environmentally sustainable ways' – which, according to Sandler, should be the ultimate goal of any emerging technology (Sandler 2009).

Therefore, in stressing the relevance of questioning the geoengineering scientific worldview, this paper aims to suggest possible ways of unveiling the complexity of the broader scientific, political and social context in which the geoengineering debate is taking place.

The Complex World of Geoengineering: Moving between Scientific Terminology and Scientific Ideology

Despite the diversity of positions adopted in the debates on geoengineering, there is widespread agreement on the need to consider the far-reaching ethical questions raised by intentional climate change proposals. However, if there is a decision to embark on this ambitious task, a major effort should be made to scrutinise and gain a better understanding of the geoengineering scientific worldview.

To be properly understood, geoengineering proposals must be linked with the larger social imaginary of science and technology in which geoengineering narratives are rooted. One way of looking at the geoengineering issue and the scalar dislocations that it introduces into modern systems of experience and understanding is to explore the close affinity that intentional climate change proposals have with many other technologies that have emerged in the recent past.

However, before we proceed along this route, we must first clarify what is meant by ‘geoengineering’, a term on which the scientific community seems far from reaching a consensus, as has been pointed out by several authors and was made clear at the aforementioned IPCC expert meeting:

> A substantial amount of time in the Expert Meeting was spent in discussing terminology in and around geoengineering. This underlines the ambiguities associated with the term geoengineering and the range of opinions on the subject. (Edenhofer et al. 2012, 2)

One of the first attempts to clarify the ambiguity of the term was made in 1996 by Thomas Schelling, who identified the features that geoengineering seems to imply: global, intentional and unnatural interventions (Schelling 1996).

Four years later, David Keith built on this attempt by pointing out the three core attributes that should serve as ‘markers of geoengineering’ actions: the scale (global or continental), the intent (the deliberate nature of the action rather than a side effect of it) and the degree to which the action is a countervailing measure (Keith 2000).

The reasons for replacing the ‘unnatural’ features by the ‘degree to which the action is a countervailing measure’ were not properly explained − even though this had implications for the type of proposals that the term encompasses[2]. Nevertheless, these three markers seem to translate the meaning of the term geoengineering, as commonly used by the scientific community nowadays, furthering the conceptual distinction between geoengineering proposals and other responses to climate change.

But even if these markers draw attention to the ‘continuum of human responses to the climate problem’ (Keith 2000) − helping to reduce the fuzziness in the conceptual distinction between geoengineering methods and other proposals to tackle climate change − there is still no consensus on specific interventions that fall within the definition of geoengineering[3].

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[2] In order to exemplify these implications it seems appropriate to refer briefly to the use of weather modification techniques (such as cloud seeding and hurricane suppression) that are taking place in many countries around the world. As recently stated by the World Meteorological Organisation: ‘since the 1980’s there has been a decline in support for weather modification research, and a tendency to move directly into operational projects’ (WMO 2010). Given the similarities between weather modification (WM) techniques and some geoengineering methods, the concerns raised by the increasing number of WM operational programmes (fog dispersion, rain and snow enhancement and hail suppression) have gained momentum in the context of the contemporary debates on geoengineering – leading, almost inevitably, to a discussion on the criteria that differentiate these two domains. However, although widely mentioned, the scale marker seems to be insufficient to exclude WM techniques from the vast range of methods that the term geoengineering encompasses. This becomes clear from the way the ‘countervailing measure criterion’ has been evoked, namely by drawing attention to the differences between ‘weather’ and ‘climate’ modification techniques, and to the far-reaching consequences of the latter: ‘Weather modifications such as cloud seeding which affect the weather for no longer than a season, in our view, do not fall within the definition of geoengineering (…) We conclude that weather techniques such as cloud seeding should not be included within the definition of geoengineering used for the purposes of activities designed to effect a change in the global climate with the aim of minimising or reversing anthropogenic climate change’ (UK House of Commons. Science and Technology Committee 2010, 15). Nonetheless, it is telling that according to this same report: ‘Cloud seeding could affect climate when carried out over a long period’ (Idem).

[3] Of which a concrete example is provided by Decision X/33 of the tenth meeting of the Conference of the Parties (COP10): ‘Without prejudice to future deliberations on the definition of geo-engineering activities, understanding that

Moreover, in considering the ethical issues raised by intentional climate change proposals, it becomes clear that these markers tend to hinder the various values, rationales and theoretical assumptions underlying the range of Carbon Dioxide Removal techniques (CDR) and Solar Radiation Management techniques (SRM) considered under the broad umbrella of the term geoengineering. As mentioned by Gardiner, the ethical discussion of geoengineering is made more difficult by the complexity of the terrain:

> First, a number of interventions are already being proposed for combating climate change, and it is not clear that all of them should be classified together. For example, some suggest deflecting a small percentage of incoming radiation from the sun by placing huge mirrors at the Legrange point between it and the earth, some advocate fertilizing the oceans with plant life to soak up more carbon dioxide, some suggest a massive program of reforestation, and some propose capturing vast quantities of emissions from power plants and burying them in sedimentary rock deep underground. But do these interventions raise the same issues? Should we count all of them as 'geoengineering'?(Gardiner 2010, 285)

To overcome the obstacles raised by the broadness of the term, Bunzl appeals to the methodological distinction between small 'g' proposals and big 'G' proposals[4]. According to the author, this distinction is fundamental for deconstructing some of the common arguments made for advancing further and faster in geoengineering research. In fact, because big 'G' proposals fall into a specific class of scientific endeavours (where the object of interest is not 'modular' or 'encapsulated'), they generate a set of methodological challenges, allowing the moral argument as to 'whether research should be done' (the permissibility of research), to give way to the methodological argument as to 'whether it could be done' (the feasibility of research) − thus shifting the burden of proof towards the proponents of geoengineering.

> But what if the object of your interest is not modular or encapsulated? What do you do then? For that, after all, is the feature that big 'G' geoengineering proposals have in common. They call for interventions on systems that lack just this characteristic. You cannot encapsulate part of the atmosphere and it is too complex to be able to build a realistic non-virtual model at scale. As such, it is reasonable to ask whether we could ever have a sound basis for moving to full deployment of any such proposed intervention. And if not, then why bother to even research such proposals in the first place? (Bunzl 2009, 2)

It seems most reasonable to question the feasibility of geoengineering research in the light of its object of interest. Indeed, the pressure of practice under which science operates today (Carrier 2011) is giving rise to the emergence of new objects of research − ambivalent beings, hybrid products and theoretically constructed objects through which we gain a new understanding and

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any technologies that deliberately reduce solar insolation or increase carbon sequestration from the atmosphere on a large scale that may affect biodiversity (excluding carbon capture and storage from fossil fuels when it captures carbon dioxide before it is released into the atmosphere) should be considered as forms of geo-engineering which are relevant to the Convention on Biological Diversity until a more precise definition can be developed'.

[4] 'Of course there is geoengineering and then there is GEOENGINEERING. Nobody gets very wound up about the idea of planting trees or painting roofs white as instances of geoengineering—which is not to say that they will necessarily do much good. The kind of geoengineering that elicits howls of disapproval is grander than this—it is things like space mirrors, sulfur injection into the upper atmosphere, and iron fertilization of the oceans—it is the idea of intervention on a grand scale (…)' (Bunzl 2009).

control of nature − that call for a more careful consideration of the complex narratives and practices of science and technology (Funtowicz and Ravetz 1993, 1994b, 1994a; Latour 1987; Haraway 1997; Law 2002; Michael 2006).

Following this appeal, some authors have suggested that it is precisely at the level of these objects of research that we can find the meaningful distinction between science and technoscience, an ontological difference that 'becomes more explicit when research results are presented in particular settings and when the objects of research are exhibited for the specific interest they hold' (Bensaude-Vincent et al. 2011, 365).

Accordingly, to expand on an example provided by these authors, it could be said that when the result of a global climate model experiment is presented as scientific evidence for understanding the importance of aerosol forcing on the climate system, this would conform to traditional conceptions of science. However, when sulphate aerosols are presented for their capacity to counteract the climate forcing of growing CO_2 emissions, this should be seen as a 'hallmark of technoscience'.

Though Bunzl's argument has the merit of drawing attention to often neglected epistemological, methodological and ontological dimensions of science and technology, it seems difficult to sustain the assumption that a solution can be found without considering the moral issues encompassed in the question 'whether research should be done'.

Indeed, the dualistic viewpoint from which the moral and methodological arguments were presented seems to neglect that the process of risk calculation is not objective, that 'risk statements are neither purely factual claims nor exclusively values claims', but something akin to a 'mathematicised morality' (Beck 2000, 215). Ultimately, the most intense and stormy controversies over science and technology are more to do with 'moral uncertainties' − the lack of commonly-shared normative yardsticks to underpin collective decision-making − than with the uncertainties about the impacts and risks those developments may raise (Hansen 2010).

Moreover, if a good case could be made for the soundness of the methodological argument, it would imply, to some degree, consideration of the moral issues relegated to the first argument. In fact, and without questioning the truth of the first premise – i.e., that GEOENGINEERING proposals fall within a specific class of scientific endeavours where the object of interest is not modular and encapsulated – the soundness of the methodological argument is rather questionable in view of its second premise – i.e., that the full deployment of this kind of intervention relies on having a sound [scientific?] basis. Quite apart from the ambiguity that the term 'sound basis' encompasses, a brief look at the history of science and technology is enough to show that the acceptance of this premise is far from being consensual. One reason is because it disregards the profound reorientation of technoscientific practices in contemporary societies – in what has been seen as a major shift from the 'laboratory ideal' to the 'field ideal' of experimentation:

> The laboratory ideal involves designing manipulated, well-controlled, isolated experimental systems; the field ideal acknowledges their complexity, blurred boundaries, and unpredictable responses to interventions. Field experiments could hardly be called an alternative ideal if they had not undergone a reevaluation in the philosophy of science and a reassessment with regard to their social relevance. We suggest that both changes can be observed especially well in the 1980s in the domain of the environmental sciences. Even if field experiments were not entirely new at that time, environmental concerns in science and society gave them a new cognitive status, institutional backing, and a specific rhetorical image. Today we are seeing the spread of new styles of experimentation to many areas of society. Experiments performed in *open spaces* might be, say, a social reform or a medical treatment, an ecological remediation or a technological innovation. (Schwarz and Krohn 2011, 120)

Another reason is that it mirrors the fact-value dichotomy, thus neglecting relevant and meaningful perspectives on science and technology in the context of application (Jasanoff 2004; Nordmann, Radder, and Schiemann 2011; Carrier and Nordmann 2011; Irwin 2008; Collins and Evans 2002; Jones 2011; Balabanian 1994). To cite just one example:

> For understanding the new tasks and methods of science, we can fruitfully invert Latour’s metaphor, and think of Nature as reinvading the lab. We see this in many ways; for example, our science-based technology, which for a while appeared to be a new man-made Nature dominant over the old, is now appreciated as critically dependent on the larger ecosystem in which it is embedded; and that it risks destruction of itself if that matrix becomes seriously perturbed or degraded (…) To characterize an issue involving risk and environment, in what we call ‘post-normal science’, we can think of it as one where facts are uncertain, values in dispute, stakes high and decisions urgent. In such a case, the term ‘problem’, with its connotations of an exercise where a defined methodology is likely to lead to a clear solution, is less appropriate. We would be misled if we retained the image of a process where true scientific facts simply determine the correct policy conclusions. (Funtowicz and Ravetz 1993, 742–744)

Although rather fragmented, this rough sketch highlights the complex world of geoengineering. It is a complexity that cannot be reduced to the ambiguities of the term or to the range of methods that the term encompasses, but must be considered in the context of the profound transformations that science is currently undergoing – that of the ‘earth alienation’ underlying the whole development of science in the modern age, described with great lucidity by Hannah Arendt:

> At any event, while world alienation[5] determined the course and the development of modern society, earth alienation became and has remained the hallmark of modern science. Under the sign of earth alienation, every science, not only physical and natural science, so radically changed its innermost content that one may doubt whether prior to the modern age anything like science existed at all. (Arendt 1958, 264, footnote added)

Geoengineering within Epochal Breaks – Two Broad Perspectives for Questioning the Geoengineering Scientific Worldview

As explained in the previous section, different conceptions, understandings and value assumptions about science and technology tend to shape the geoengineering debate and inform the analytical framework within which the geoengineering domain has been problematised. This reinforces the need to unbind geoengineering discourses from the deeply embedded narratives of science, technology and society that put forward technoscientific innovation as the solution to our most critical problems and as a substitute for social change (Ulrike Felt et al. 2007). Looking at geoengineering from a more distant and detached point presupposes considering it from a broad, long-term perspective, both in terms of the human-environment relationship, and in terms of the relationships between science, technology and society.

The following introduces and analyses two different conceptual frameworks from which the two fundamental questions under discussion may be addressed. The first represents the mainstream Earth System Science perspective, while the second corresponds to an alternative (though compatible) view from the field of social studies of science and technology. Central to

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[5] i.e. ‘the distance which man puts between himself and the world’ (Arendt 1958, 252).

both is the concept of an ‘epochal break’: for the former in terms of the Human-Earth relationship, for the latter in terms of the relationship between science, technology and society.

The Earth System Science Perspective – The Anthropocene: An Epochal Break in the Human-Earth Relationship

Over the past 150 years, several efforts have been made to document and understand the interaction of human and environmental systems from a long-term, global perspective.

George Perkins Marsh’s remarkable work ‘Man and Nature; or Physics Geography as Modified by Human Action’, first published in 1864, has been widely acknowledged by environmental scientists as the first comprehensive analysis of the detrimental effects of human modification on the natural environment (Krech, McNeill, and Merchant 2004). Marsh drew on examples from around the world to provide a comprehensive description of the major changes produced by human action on the earth’s surface – ‘the history of man’s industry as exerted upon Animal and Vegetable Life, upon the Woods, upon the Waters, and upon the Sands’ (Marsh 1864, vi) – and to stress the need for caution in all human interventions which, on a large scale, interfere with the laws of nature. In the last chapter, he presents some of the major ‘geographical revolutions’ projected at that time (among them Epsy’s theory for artificial rainmaking), and concludes that ‘(…) every new fact, illustrative of the action and reaction between humanity and the material world around it, is another step toward the determination of the great question whether man is of nature or above her’ (Marsh 1864, 549).

The second major effort to examine the geographically and historically cumulative effects of man on Earth was undertaken in an international symposium sponsored by the Wenner-Gren Foundation for Anthropological Research, held in Princeton in June 1955. The symposium was organised by the Foundation assistant’s director, William L. Thomas Jr., with the collaboration of Carl O. Sauer (chairman of the symposium), Marston Bates and Lewis Mumford. Under the broad themes of ‘retrospect’, ‘process’, and ‘prospect’, the symposium aimed to explore, in a holistic and integrative way, the question: ‘What has been, and is, happening to the earth’s surface as a result of man’s having been on it for a long time, increasing in numbers and skills unevenly, at different places and times?’ (Thomas Jr. 1956, viii). The symposium volume ‘Man’s Role in Changing the Face of the Earth’ was published in 1956 and includes the essays of 53 contributors from a wide variety of disciplines, as well as the reports on the symposium discussions. Written more than half a century ago, this landmark work represents an early and valuable account of contemporary environmental concerns, which, along with ‘A Sandy County Almanac’ (Leopold 1949), seems to set the stage for the emergence of the ecological movement of the 1960s.

Although favouring the quantitative aspects of human-induced environmental transformations, and paying less attention to its cultural and historical dimensions, during the next three decades the number of global environmental studies multiplied, contributing to an increased understanding of the magnitude of those transformations and the processes responsible for them (Kates, B. L. Turner II, and Clark 1990). The maturation of scientific knowledge about the Earth, advances in space-based Earth observation technologies and increasing awareness of how humans are modifying the environment have contributed to a new understanding of the Earth – as an integrated system, whose study must transcend disciplinary boundaries – leading to the development of NASA’s research approach to Earth System Science[6], which has become the backbone of many global research initiatives around the world (ESSC 1988).

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[6] This research approach consists of four steps: i) observation, ii) analysis and interpretation, iii) models, and iv) verification and prediction.

In 1990, with the publication of 'The Earth as Transformed by Human Action' (B. L. Turner II et al. 1990), a major scientific effort was made to provide new insights and a broad overview of the full array of human impacts on Earth. Drawing upon significant developments in science[7], this work aimed not only to recover and tell 'the general story of how humankind has remade the planet on which it lives' (Meyer 1996), but also to address a deeper and more fundamental question: 'What is and ought to be the relationship of humans to the earth?' (Kates, B. L. Turner II, and Clark 1990, 2).

Over the last two decades, research into the growing interference of human action with the Earth system has achieved considerable progress. There was a major boost to developing interdisciplinary global change research in 2001[8], with the establishment of the Earth System Science Partnership (ESSP), which has brought together the four international global change research programmes: DIVERSITAS; the International Geosphere-Biosphere Programme (IGBP); the International Human Dimensions Programme (IHDP); and the World Climate Research Programme (WCRP).

In the course of these developments, a new concept – the Anthropocene – has emerged to capture the quantitative shift in the relationship between humans and the global environment, thus potentially marking the beginning of a new geological epoch (Steffen, Grinevald et al. 2011).

The term Anthropocene first appeared in print in 2000, in a newsletter of the IGBP (Crutzen and Stoermer 2000). Two years later, a related article from the Nobel Laureate Paul Crutzen was published in the journal *Nature*, in which he notes that:

> Unless there is a global catastrophe – a meteorite impact, a world war or a pandemic – mankind will remain a major environmental force for many millennia. A daunting task lies ahead for scientists and engineers to guide society towards environmentally sustainable management during the era of the Anthropocene. This will require appropriate human behaviour at all scales, *and may well involve internationally accepted, large-scale geo-engineering projects, for instance to 'optimise' climate.* At this stage, however, we are still largely treading on *terra incognita.* (Crutzen 2002, emphasis added)

The implications of recognising this newly-constructed concept go beyond the discussions around 'golden spikes' and stratigraphic criteria that aim to examine whether there is, in geological terms, a justification or need for the formal adoption of a new geological epoch (Zalasiewicz et al. 2008). As is clear from the above, the recognition of this epochal break seems to require much more: i) concerted efforts on part of scientists and engineers to achieve effective planetary stewardship; ii) substantial and effective behavioural change in the most advanced societies towards more sustainable lifestyles; iii) and the acceptance of large–scale geoengineering projects at the international level. The responses to these appeals have been swift and generous, reflecting the broad acceptance of the Anthropocene concept in the global change research community and the way it has been assumed as a central system of thought for Earth System Science – one that 'works upon our identities and enables new ways of being in and acting upon nature and society' (Lovbrand, Stripple, and Wiman 2009).

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[7] '(1) new ways to conceptualize the unity of the biosphere, symbolized by the wide currency of the term itself; (2) new ways and collective efforts to acquire data and analyze their detail and complexity; and (3) reassessment of some of the avenues that link social behavior with environmental transformations' (Kates, B. L. Turner II, and Clark 1990).

[8] The ESSP was launched in 2001 as a response to the Amsterdam Declaration on Global Change, which called for strengthening cooperation among the global environmental research programmes, for greater integration across disciplines, environment and development issues and the natural and social sciences.

Indeed, since the beginning of this century the Anthropocene has been widely discussed and has become an active area of research into global environmental change. New institutional frameworks for sustainable development and fundamental reforms of national and international institutions towards more effective planetary stewardship and earth system governance are being forged (Biermann, Abbott, Andresen, Bäckstrand, Bernstein, Betsill, Bulkeley, Cashore, Clapp, Folke, Gupta, Gupta, Haas, Jordan, Kanie, Kluvánková-Oravská et al. 2012; Biermann and Pattberg 2012; Biermann, Abbott, Andresen, Bäckstrand, Bernstein, Betsill, Bulkeley, Cashore, Clapp, Folke, Gupta, Gupta, Haas, Jordan, Kanie, Kluvánková-Oravská et al. 2012; Schellnhuber et al. 2004).

Innovative approaches to identify 'guardrails' for responsible planetary management (Petschel-Held et al. 1999) and to quantify biophysical preconditions for human development in the Anthropocene have led to the definition of 'planetary boundaries', i.e. the 'safe operation space for humanity' with respect to the Earth system, within which humanity has the freedom to pursue long-term social and economic development, as long as thresholds are not crossed (Rockström et al. 2009a, 2009b). An increasing number of geoengineering research initiatives are opening up new approaches to tackling climate change and possible ways of overcoming those 'non-negotiable' planetary boundaries. Lastly, several efforts have been made 'to push geoengineering up the international agenda' (UK House of Commons. Science and Technology Committee 2010; GAO 2011; Ginzky et al. 2011) and to consider policies and strategies for addressing geoengineering at national and international levels (Bracmort, Lattanzio, and Barbour 2011). In this context, it seems that the fundamental frame[9] to mobilise support for an alteration of social structures and agents' social values, and to persuade wider society to adopt responsible behaviour on the basis of a proposed normative human response to climate change, is the only element that is still missing. A circumstance that shows which end of the spectrum of required transformational approaches posed by the Anthropocene[10] has been favoured and how its imagery 'both challenges and reproduces the Enlightenment promise of human self-realisation, autonomy and control' (Lovbrand, Stripple, and Wiman 2009, 8).

An STS Perspective – An Epochal Break in the Science-Technology-Society Relationship

As previously discussed, the new integrative framework of Earth System Science to monitor human-induced transformations on the global environment, gain a better understanding of the direct and indirect processes underlying these transformations and develop the ability to estimate the past and future trajectories of those changes, has not only provided new perspectives on 'man's role in changing the face of earth', but has also brought to light the changed nature of human action – a condition that has long been recognised, even if its full implications are still difficult to grasp.

> (…) man now is evermore the maker of what he has made and the doer of what he can do, and most of all the preparer of what he will be able to do next. But who is "he"? Not you or I: it is the aggregate, not the individual doer or deed that matters here; and the indefinite future, rather than the contemporary context of the action, constitutes the relevant horizon of responsibility. This requires imperatives of a new sort. If the realm of making has invaded the space of essential action, then morality must invade the realm

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[9] The term 'frame' is used here in the sense given by Mayer N. Zald, i.e. 'specific metaphors, symbolic representations, and cognitive cues used to render or cast behaviour and events in an evaluative mode and to suggest alternative modes of action' (Zald 1996, 262).

[10] In which 'geoengineering and reducing human pressure on the Earth System at its source represent the end points of the spectrum in terms of philosophies, ethics and strategies' (Steffen, Persson et al. 2011, 252).

> of making, from which it has formerly stayed aloof, and must do so in the form of public policy. Public policy has never had to deal before with issues of such inclusiveness and such lengths of anticipation. In fact, the changed nature of human action changes the very nature of politics. (Jonas 1984, 9)

In fact, in an almost paradoxical way, the concept of the Anthropocene, 'which cuts through a mass of complexity and detail to place the evolution of the human enterprise in the context of a much longer Earth History' (Steffen, Persson et al. 2011), seems to rest on previous efforts to understand the deeper meanings and implications of the trajectory of the human-environment relationship, to reproduce the very practices that gave rise to its high-order discontinuities, and which were precisely those that the term was sought to challenge in the first place (Lovbrand, Stripple, and Wiman 2009):

> The advent of the Anthropocene, the time interval in which human activities now rival global geophysical processes, suggests that we need to fundamentally alter our relationship with the planet we inhabit. Many approaches could be adopted, ranging from geoengineering solutions that purposefully manipulate parts of the Earth System to becoming active stewards of our own life support system. (Steffen, Persson et al. 2011, 739)

This situation draws attention to the need to look at this broad context of human-environment relationship from a perspective that takes into account the discontinuities of both a social and a technoscientific nature that have shaped the interactions between socioeconomic, technological and environmental systems, and which, in our view, can only be perceived if we consider the profound transformations that have been taking place in the relationship between science, technology and society.

> If one wishes to draw a distinctive line between the modern age and the world we have come to live in, he may well find it in the difference between a science which looks upon nature from a universal standpoint and thus acquires complete mastery over her, on one hand, and a truly "universal" science, on the other, which imports cosmic processes into nature even at the obvious risk of destroying her and, with her, man's mastership over her. (Arendt 1958, 268)

And it is precisely therein that we understand the relevance (and the necessity) of considering our second 'epochal break', 'the idea that there has been a transformation in the relation of science, technology, and society so profound that our received notions of 'science' have been superseded by something else (…) a shift from the scientific enterprise to the regime of technoscience' (Nordmann, Radder, and Schiemann 2011). From this perspective, one way of looking at the geoengineering issue and the scalar dislocations that it introduces into modern systems of experience and understanding is to explore the differences and affinities which intentional climate change proposals have in relation to many other technologies that have emerged in the recent past.

The concept of terraforming, which once made us dream about exploring and utilising other planets, seems to have been reinvented under the aegis of Earth System Science to re-centre on Earth itself the proposals for the wholesale rearrangement of a planet's environment to support human life (Fogg 1995). Like the Space Exploration enterprises of the 1970s and 1980s, geoengineering proposals change the fundamental idea of limits that underpins the environmental movement, inspiring new possibilities for exalting and expanding our current lifestyles. These are just a few examples of alternative ways of interrogating geoengineering, which, in the context of this epochal break, may ultimately be seen as an illustrative metaphor of the specific kinds of technoscientific promises and 'technofix' narratives emerging in our society.

Final Remarks – Questioning Geoengineering: Nature Changed by Human Action or Changed Nature of Human Action?

In conclusion, and to return to our two fundamental questions, we have drawn upon previous efforts to develop an integrated vision of human-environment interactions – the integration of human history with, and within, the history of the Earth on a global scale (Costanza et al. 2007, Cf. Figure 1, p. 524; Costanza, Graumlich, and Steffen 2007) – to suggest that these two epochal breaks (in terms of the Human-Earth relationship, and in terms of the relationship between science, technology and society) should constitute the fundamental axes from which a fully integrated history of geoengineering should be told and analysed. It is a history that not only places the evolution of this (and other) enterprise(s) in the context of a very long Earth history – *nature changed by human action* – but critically reflects upon it, to understand and interpret fundamental transformations in the relationships between science and society, science and nature, and science and technology (Carrier and Nordmann 2011) – *changed nature of human action*.

Indeed, the history we are talking about is not only the history of geoengineering, the Anthropocene or the major epochal-making realignment of science and technology in society; it is the history of human action, in which scientists have become passionate protagonists of their individual beliefs, enlarging 'the realm of human affairs to the point of extinguishing the time-honoured protective dividing line between nature and the human world' (Arendt 1958). But because this capacity for action has become 'the exclusive prerogative of the scientists' (idem), it lacks the revelatory capacity to illuminate the realm of human affairs in its specific phenomenal reality, and to endow this reality with meaning (Villa 1996):

> But the action of the scientists, since it acts into nature from the standpoint of the universe and not into the web of human relationships, lacks the revelatory character of action as well as the ability to produce stories and become historical, which together form the very source from which meaningfulness springs into and illuminates human existence. In this existentially most important aspect, action, too, has become an experience for the privileged few, and these few who still know what it means to act may well be even fewer than the artists, their experience even rarer than the genuine experience of and love for the world. (Arendt 1958, 324)

In the context of these 'policy vacuums', characterised by 'a growing sense of urgency coupled with a lack of knowledge of what to do and a lack of institutions where the issues could be addressed' (Rommetveit, Funtowicz, and Strand 2010, 150), the recurrent claims that argue for a closer connection between science and society, with the purpose of exposing to public scrutiny the hidden assumptions, values and visions that are deeply embedded in science and technology, seem more than justified.

For science and technology studies (STS) the far-reaching implications of those claims rely in a set of 'boundary concepts' (Irwin 2008), of which we highlight the concept of coproduction, that suggests that the 'products of technoscience not only influence but also incorporate and reaffirm social values and institutional practices' (Jasanoff 2011, 13), and which draws attention to 'the often invisible role of knowledge, expertise, technical practices and material objects in shaping, sustaining, subverting or transforming relations of authority' (Jasanoff 2004, 4).

This explanatory power of thinking of natural and social orders as being produced together leads the participatory ideals of public engagement, with all the reservations pointed out by Wynne (2007), far beyond narrow perspectives of problematising the relationship between science and democracy. Indeed, a more sophisticated model of public engagement with science

(PES) and technology has been suggested for some time, one that acknowledges that ‘public engagement needs to move upstream’ to consider new ways of listening to and valuing more diverse forms of public knowledge and social intelligence (Wilsdon and Willis 2004; Felt and Fochler 2009). The basic assumption underlying the notion of ‘upstream public engagement’ relates with the necessity of replacing the one-way normative model of public ‘understanding’ of (or ‘deference’ to) science (Wynne 2007, 100) to a more substantive model of engagement, which aims at creating more socially-robust scientific and technological solutions by way of opening up questions, furthering debates, exposing differences and interrogating assumptions.

The ultimate challenge is ‘to generate new approaches to the governance of science that can learn from past mistakes, cope more readily with social complexity, and harness the drivers of technological change for the common good’ (Wilsdon and Willis 2004, 24). What seems to be at stake is not only the need to clarify the assumptions and arguments that sustain the positions that tend to stick between hope and fear on science and technology – ‘For those promoting the technologies, such developments hold promises of a better world, for the sceptics they entail Faustian dangers and embody a lot of what is wrong with the modern world’ (Hansen 2010, 1) – but to go beyond these polarised positions to further explore the context of political uncertainty, public debate and societal decision-making in which science and technology have been operating (Irwin 2008).

Against this background many authors have been arguing about the importance of considering public perceptions of geoengineering, thus helping to further unveil the perceived moral orders underlying these proposals (Bracmort, Lattanzio, and Barbour 2011; Miller 2010a, 2010b; The Royal Society 2009; Cicerone 2006; Pidgeon et al. 2012; Corner, Pidgeon, and Parkhill 2012; Corner and Pidgeon 2010; Poumadere, Bertoldo, and Samadi 2011; Mercer, Keith, and Sharp 2011; Nerlich and Jaspal 2012).

Therefore, in supporting the need to subject the scientific debate on geoengineering to more open and critical reflection, we highlight the importance of rebuilding the ‘geoengineering scientific worldview’ on social processes of trust and credibility, in this way impelling climate change science to better reveal competing social interests, values and assumptions (Irwin and Wynne 1996). We also see this as an opportunity to promote critical thinking about social problems that tend to be ‘circumvented’ and reduced to technological fixes (Weinberg 1991), thus ‘alienating’ and ‘diverting’ our attention from an essential question, that of our place in nature.

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* The views expressed in this paper are those of the author and do not necessarily represent the official views of the European Commission.

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Towards an Analytical Framework for Evaluating the Ethical Dimensions of Geoengineering Proposals

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Abstract: Over the last few years, geoengineering, or the 'deliberate large-scale intervention in the Earth's climate system in order to moderate global warming', has been attracting increasing attention within the portfolio of strategies to limit the impact and consequences of climate change. However, this 'Plan B' is inevitably conditioned by our limited understanding of the scientific basis of climate change and by major uncertainties as to the impact geoengineering might have on human and natural systems. Therefore, in spite of the controversy prevailing in the debates surrounding geoengineering technologies, there is widespread agreement on the need to consider the far-reaching ethical and social questions that proposals for intentional climate change entail. Although some attempts have been made to address this need (and to further ethical awareness in the scientific community), an ethical framework that could inform policy responses to geoengineering research, deployment and governance has yet to be developed. The overall objective of this paper, therefore, is to address the need to develop an analytical framework that can contribute to a better understanding of the ethical and social issues raised by geoengineering proposals and serve as a basis for further analysis, with a view to developing and implementing appropriate governance mechanisms to steer geoengineering research and deployment.

Keywords: Geoengineering, Ethical Framework, Climate Change, Earth System Science, Epochal Break, Anthropocene

What Makes Geoengineering an Ethical Issue?

Over the past decade, geoengineering has been gaining momentum in the climate change community. This growing interest in '*deliberate large-scale intervention in the Earth's climate system, in order to moderate global warming*' (Royal Society 2009) is closely linked to the '*grossly unsuccessful'* efforts to reduce greenhouse gas emissions (Crutzen 2006) and the consequent urgent need to consider additional steps to address global climate change.

However, the understanding of the physical science basis of geoengineering is still limited, and there are still major uncertainties concerning the impacts these technologies might have on human and natural systems. Therefore, in spite of the controversy prevailing in the debates surrounding geoengineering technologies, there is widespread agreement on the need to consider the far-reaching ethical and social questions that proposals for intentional climate change entail.

Against this background, the development of new geoengineering research initiatives, the rapid expansion of the scientific literature in the field and the growing number of policy reports over the past few years not only reveal the ever more plausible role that solar radiation management (SRM) and carbon dioxide removal (CDR) methods are likely to play in the portfolio of solutions to address climate change, but also reflect the growing concerns about the ethical and social issues that we need to address when considering the use of these technologies to avert the climate crisis.

At first glance, these two trends may suggest different forces pushing in opposite directions: on the one hand, the plausibility of geoengineering proposals, grounded in factual or empirical statements, seems to act as a catalyst for further research and deployment, while on the other hand normative concerns over unforeseen consequences, including controllability and reversibility – and other value judgments about the impacts on perceived naturalness and in terms of fairness and equity (Macnaghten and Chilvers 2012), seem to lie behind a reluctance to take these activities seriously. However, as we will try to show below, the reality is far more complex than this.

In fact, as was made clear in the comprehensive study of climate engineering debates commissioned by the German Federal Ministry of Education and Research (BMBF), the very different arguments that have been advanced for and against geoengineering, and the complex interplay between them at different levels of detail, reveal the rather complicated and entangled relationships between ‘is’ and ‘ought’, facts and values, descriptive and normative, epistemic and material:

> ‘On the one hand, the arguments make use of empirical assumptions which can be assessed scientifically. On the other hand, they always rely on more or less far-reaching normative premises, as well. Such normative assumptions may involve the weighting of side-effects or the moral assessment of inequalities; in any case, they evade an empirical, scientific evaluation’ (Rickels et al. 2011, 32).
>
> ‘Within the CE [climate engineering] controversy, moral and extra-moral considerations seem to be deeply interwoven. This is mainly due to the fact that the moral arguments also make use of descriptive premisses such as forecasts of an action’s consequences’ (Betz and Cacean 2012, 66).

It is precisely this characteristic of the controversial debate on climate engineering that provides the first part of the answer to our initial question: What makes geoengineering an ethical issue? A closer examination of the arguments that support the main theses and sub-theses of the geoengineering debate throws light on how issues tend to be discussed with reference to the ethical questions they pose – in terms of justice, intergenerational equity, responsibility, fairness and the like, thus conforming to a common-sense understanding of ‘*what makes an issue an ethical issue*’:

> ‘… we can usefully distinguish between issues that are discussed and resolved with reference to the ethical questions they pose and issues debated on other grounds. The former are those discussed in terms of moral ideas, such as dignity, freedom, rights, fairness, respect, equality, solidarity, responsibility, justice, and integrity. Some of these are personal virtues, others are features of social life; some are powers, others ideals. What they have in common is that they are mentioned when one tries to speak of right and wrong, and that they are invoked in discussions that go beyond assertions about facts and descriptions of events to claims about why things *ought* to be done in certain ways or what *ought* to be done’ (Bulger, Bobby, and Fineberg 1995, 28).

Although useful, this distinction does not allow us to draw any meaningful conclusion about the particular conceptualisations of geoengineering, research practices in this field, or the prospects of a ‘geoengineered world’ that invoke the set of ethical principles and moral values previously mentioned. Thus, the main objective of this paper is to lay the foundations for a comprehensive analytical framework within which the social and ethical issues raised by geoengineering proposals could be examined.

Moreover, because no consensus has yet been reached as regards the development of an adequate theoretical framework to guide the resolution of ethical problems and moral dilemmas arising from geoengineering research and deployment, the design of this analytical framework should not only facilitate the examination of those problems, but also help to establish an integrated approach to promote discussion and provide general guidelines for ethically responsible decision-making in the field of geoengineering.

Indeed, since ‘*all approaches to geoengineering express an implied ontology (an embedded theory of who we are, how we are situated in the realm of being) and a presumed ethics (an embedded theory of how we ought to behave)*’ (Weiskel 2012), we suggest that only within the development of a systematic discourse involving ethics – as accompanying research (*Begleitforschung*) (Hronszky 2005) – can the following far-reaching preliminary questions be addressed:

- How will geoengineering technologies improve the human condition now and in the long term?
- What are the theoretical assumptions, motivations, and interests relating to the development of different geoengineering methods?

- What goals and visions tend to shape the methods and practices of science in the field of geoengineering?
- What 'imaginaries', commitments and representations of nature and of the human being inform geoengineering debates?
- What are the expectations, the embedded values and the ways of making sense of a geoengineered world?

In order to address these issues, it will first be necessary to find an adequate vantage point from which the fundamental aspects underlying these questions might become visible. In the following section, we will therefore begin with an attempt to identify and summarise the key elements of the strategic framework for global environmental change research within which geoengineering is taking place. This approach will provide some fundamental background for the outline of our proposed framework, as presented in section 3 and further discussed in section 4 of this paper.

Geoengineering at the Dawn of a New Era – The Anthropocene and a New System of Science

In the mid-1980s, when the Earth System Sciences Committee of the NASA Advisory Council put forward a more complete and unified approach to Earth studies – Earth System Science – a new way of understanding and analysing the Earth system began to gain ground among scientific institutions around the world. Fundamental to this approach is a view of the Earth system as a related set of interacting processes operating on a wide range of spatial and temporal scales, rather than as a collection of individual components. Several factors have combined to stimulate this new approach to Earth studies and global change: the maturity of the traditional Earth science disciplines, developments in remote sensing systems and related earth observation activities, advances in conceptual and numerical models of Earth system processes, and the recognition of the growing role of human activity in global change (Earth System Sciences Committee 1988, 1986).

A few years after NASA acknowledged the need to strengthen international cooperation for a truly worldwide study of the Earth, the Rio Declaration on Environment and Development and Agenda 21 (a comprehensive plan of action to facilitate the transition towards the goal of truly sustainable development), unanimously adopted by 178 Governments at the United Nations Conference on Environment and Development (UNCED), gave a major boost to the development of an integrated approach to sustainable development and for the interdisciplinary focus of Earth system science and global change (Johnson, Ruzek, and Kalb 1997).

The next important step towards a holistic perception of the Earth system as a whole and, on this cognitive basis, developing concepts for global environmental management was taken in 2001 with the establishment of the Earth System Science Partnership (ESSP), which brought together the four international global change research programmes: DIVERSITAS, the International Geosphere-Biosphere Programme (IGBP), the International Human Dimensions Programme (IHDP), and the World Climate Research Programme (WCRP)[1].

The orchestrated effort to integrate disciplinary knowledge, insights and understanding of parts of the Earth system within Earth system science gave rise to the idea of a '*global system of global systems science*'. Seen as a '*substantive science of integration'*, this new system of global environmental science is today presented as the key to implementing any approach towards global sustainability (Steffen et al. 2004).

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[1] The ESSP was launched in 2001 as a response to the Amsterdam Declaration on Global Change, which called for closer cooperation between global environmental research programmes and for greater integration across disciplines, environment and development issues, and the natural and social sciences.

> ‘The challenge of understanding a changing Earth demands not only systems science but also a **new system of science** …
>
> Human-driven changes are pushing the Earth System beyond its natural operating domain into planetary *terra incognita*. Management strategies for global sustainability are urgently required. **Earth System science is the key to implementing any approach towards good planetary management**, as it can provide critical insights into the feasibility, risks, trade-offs and timeliness of any proposed strategy’ (Global Environmental Change Programmes 2011, 23-27, emphasis added).

This new way of understanding and studying the Earth system, the recognition that humanity itself has become a global geophysical force, allied with new approaches and a growing commitment to achieving successful and effective planetary stewardship, are leading to a profound reorientation of the global environmental change research agenda, thereby opening up a wide range of new practices, techniques and mechanisms for global governance.

> ‘The advent of the Anthropocene, the time interval in which human activities now rival global geophysical processes, suggests that we need to fundamentally alter our relationship with the planet we inhabit. Many approaches could be adopted, ranging from geoengineering solutions that purposefully manipulate parts of the Earth System to becoming active stewards of our own life support system’ (Steffen et al. 2011, 739).

It is against this background that the idea of geoengineering, as a potential new tool for addressing climate change, is gaining ground. Hence, the first step towards establishing our analytical framework should consist in a critical examination of the salient narratives that capture the quantitative shift in the relationship between humans and the global environment, in order to suggest the beginning of a potential new geological epoch in which human beings appear to have become a driving force in the evolution of the planet and geoengineering starts to look acceptable, if not attractive.

In fact, each new step in the direction of an integrated Earth system science seems to have reinforced the plausibility of geoengineering proposals within the wide range of options ‘*towards good planetary management*’ (Global Environmental Change Programmes 2011). This is made clear by considering the impetus for geoengineering that came from novel structural concepts of Earth system science. It is therefore worth examining the intrinsically prescriptive nature of concepts such as ‘*climate stabilisation*’ and ‘*Anthropocene*’ in some detail, as they seem to provide the ontological and epistemological underpinnings that brought geoengineering to the centre of the climate change debate.

In 1974, William Kellogg and Stephen Schneider published an article in *Science*, entitled ‘Climate Stabilization: For Better or for Worse?’, which presented the three options we would have if we could forecast climate changes: i) to do nothing; ii) to alter our patterns of land and sea use in order to lessen the impact of climate change; or iii) to anticipate climate change and implement schemes to control it. In the context of this last option, the authors discuss the concept of climate stabilisation and the concomitant problems of predicting ‘*what will happen if we try to influence part of the climate system*’ and of defining ‘*the “optimum climate” towards which we should aim our stabilization schemes*’ (Kellogg and Schneider 1974). The early summary of various stabilisation schemes presented by the authors does not differ from many of the geoengineering methods that are being discussed today. Similarly, their insights about how developing skills to predict climate change might generate pressure to stabilise the climate could well describe some of the less widely discussed (but nevertheless far-reaching) implications of important advances in climate modelling and climate science in recent years towards the idea of greater planetary management and Earth-system control. Though emphasising the major uncertainties, contentions and political ramifications of the third option, Kellogg and Schneider drew attention to the possibility ‘*that more schemes will be proposed for climate control than for control of the climate* *controllers*' – thus anticipating and discussing a wide range of governance challenges associated with recent proposals to geoengineer the climate.

Twenty-five years later, in a landmark paper for Earth system science published in the journal *Nature,* Hans J. Schellnhuber presented the five competing paradigms for sustainable development and Earth-system control: (1) Standardisation — prescribing a long-term co-evolution corridor; (2) Optimisation — maximising an aggregated anthroposphere-ecosphere welfare function; (3) Pessimisation — avoiding the worst under imperfect management; (4) Equitisation — preserving options for future generations; and (5) Stabilisation — landing and maintaining the Earth system in a desirable state (Schellnhuber 1999). Although involving very different ways of perceiving and evaluating man's attempts to 'act into nature', these competing paradigms have been incorporated, to a certain extent, into Earth system thinking, creating tensions in the range of practices that have produced the 'coupled human and ecological system' as a 'thinkable' and governable domain (Lovbrand, Stripple, and Wiman 2009).

These tensions can be captured by examining the formal elaboration of these paradigms and the attempts that have been made to put them into operation. For instance, the least speculative paradigm of pessimisation, the formal elaboration of which presupposes the compiling of a manual of minimum safety standards for operating the Earth system (the 'guardrails' for responsible planetary management), clearly contrasts with the paradigm of stabilisation[2], where geoengineering tends to be seen as one of the least sophisticated options for landing and maintaining the Earth system in a desirable state:

> 'Why should Prometheus not hasten to Gaia's assistance? Geoengineering proposals have become popular as a way of mitigating the anthropogenic aberrations of the ecosphere. One interesting idea features iron fertilization of certain ocean regions to stimulate the marine biological pump which draws down CO_2. And Russian scientists are currently elaborating a repair scheme for the ozone layer using orbital lasers. But we can also think of proactive control of natural planetary variability: insights acquired during the present climate crisis may enable humanity to suppress future glaciation events by judicious injection of "designer greenhouse gases" into the atmosphere' (Schellnhuber 1999, C23).

The way these different strategies for sustainability have been embedded in Earth system thinking, leading to a definition of the 'accessible universe' and a heterogeneous set of practices that shape the political space for government intervention, can also be seen by examining how the 'Anthropocene' imagery entails different ways of being and acting upon nature and society (Lovbrand, Stripple, and Wiman 2009).

The term 'Anthropocene' first appeared in print in 2000, in a newsletter of the IGBP (Crutzen and Stoermer 2000). In 2002, *Nature* published a related article by Nobel Laureate Paul Crutzen (who brought the discussion of geoengineering more squarely into public view four years later (Crutzen 2006; Pielke, Roger, Jr. 2010)), in which he noted that:

> 'Unless there is a global catastrophe — a meteorite impact, a world war or a pandemic — mankind will remain a major environmental force for many millennia. A daunting task lies ahead for scientists and engineers to guide society towards environmentally sustainable management during the era of the Anthropocene. This will require appropriate human behaviour at all scales, **and may well involve internationally accepted, large-scale geo-engineering projects, for instance to "optimize" climate.** At this stage, however, we are still largely treading on *terra incognita*' (Crutzen 2002, emphasis added).

The implications of recognising the newly constructed concept go beyond the discussions around 'golden spikes' and stratigraphic criteria that aim to examine whether there is, in geological

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[2] The title of one of the most-cited articles in the field of geoengineering, *Engineering: Advanced technology paths to global climate stability: Energy for a greenhouse planet* (Hoffert et al. 2002), suggests the relevance of this paradigm/concept to the subsequent developments in the field.

terms, a justification or need for the formal acknowledgement of a new geological epoch (Zalasiewicz et al. 2008). As the above makes clear, the recognition of this epochal break seems to require much more: i) concerted efforts on the part of scientists and engineers to achieve effective planetary stewardship; ii) substantial and effective behavioural change in the most advanced societies towards more sustainable lifestyles; and iii) the acceptance of large-scale geoengineering projects at international level. The responses to these appeals have been swift and generous, reflecting the broad acceptance of the Anthropocene concept in the global change research community and the way it has been taken up as a central system of thought for Earth system science (Lovbrand, Stripple, and Wiman 2009; Dalby 2007, 2004).

Indeed, since the beginning of this century, the Anthropocene has been widely discussed and has become an active area of global environmental change research. New institutional frameworks for sustainable development and fundamental reforms of national and international institutions towards more effective planetary stewardship and Earth system governance are being forged (Biermann, Abbott, Andresen, Bäckstrand, Bernstein, Betsill, Bulkeley, Cashore, Clapp, Folke, Gupta, Gupta, Haas, Jordan, Kanie, Kluvánková-Oravská et al. 2012). Innovative approaches to identify ‘guardrails’ for responsible planetary management (Petschel-Held et al. 1999) and to quantify biophysical preconditions for human development in the Anthropocene have led to the definition of ‘planetary boundaries’, i.e. the ‘safe operation space for humanity’ with respect to the Earth system, within which humanity has the freedom to pursue long-term social and economic development, as long as thresholds are not crossed (Rockström et al. 2009a, 2009b). An increased number of geoengineering research initiatives are opening up new approaches to tackling climate change and possible ways of overcoming these ‘non-negotiable’ planetary boundaries. Lastly, several efforts have been made to push geoengineering up the international agenda (UK House of Commons. Science and Technology Committee 2010; US Government Accountability Office 2011) and to consider policies and strategies for addressing geoengineering at national and international levels (US House of Representatives 2010; Bracmort and Lattanzio 2013). In this context, it seems that the fundamental frame[3] within which to mobilise support for an alteration of social structures and agents’ social values, and to persuade wider society to adopt responsible behaviour on the basis of a proposed normative human response to climate change, is the only element that is still missing. This shows which end-point of the spectrum of the required transformational approaches posed by the Anthropocene[4] has been favoured.

In fact, the concept of the Anthropocene, ‘*which cuts through a mass of complexity and detail to place the evolution of the human enterprise in the context of a much longer Earth History*’ (Steffen et al. 2011), seems to rest upon previous efforts to understand the deeper meanings and implications of the trajectory of the human-environment relationship (Marsh 1864; Thomas Jr. 1956; B. L. Turner II et al. 1990), to open up a range of possible government programmes for sustainability that both challenge and reproduce the Enlightenment promise of human self-realisation, autonomy and control. Accordingly, Lövbrand, Stripple and Wiman draw attention to how the Anthropocene imagery points to inconsistencies and ruptures within the emerging Earth system governmentality[5]:

> ‘…we have identified ambiguities in the Anthropocene imagery in terms of (1) the persons over whom government is to be exercised (autonomous and rational individuals vs. ecologically embedded citizens); (2) the distribution of tasks and actions between authorities (expert-driven, central government vs. deliberative, popular control); and (3) contrasting ideals or principles for how government should be directed (control and

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[3] We use the term ‘frame’ here in the sense given by Mayer N. Zald, i.e. ‘*specific metaphors, symbolic representations, and cognitive cues used to render or cast behavior and events in an evaluative mode and to suggest alternative modes of action*’ (Zald 1996, p. 262).

[4] In which ‘*Geo-engineering and reducing the human pressure on the Earth System at its sources represent the end points of the spectrum in terms of philosophies, ethics and strategies*’ (Steffen et al. 2011, p. 752).

[5] ‘*As indicated by the semantic linking of the words governing and mentality, governmentality deals with how we think about governing*’ (Lovbrand, Stripple, and Wiman 2009, p. 8).

management vs. humility and reflexiveness) (Lovbrand, Stripple, and Wiman 2009, p. 12).

The Ethical Matrix Revisited: Towards an Ethically Sound Framework for Geoengineering

By stressing the relevance of considering the close links between thought and intervention, we draw upon the analytical concept of Earth system governmentality advanced by Lövbrand, Stripple and Wiman to suggest that the large continuum of possible government programmes for sustainability should constitute the backbone of the analytical framework outlined in this section. Moreover, as we will now see, it is also assumed that the analysis of geoengineering within this continuum might provide an adequate solution for addressing what have been tentatively agreed as the five main properties of '*ethically sound frameworks'*, namely:

a. Inclusion of values at stake – making explicit the values at stake in any decision;
b. Transparency – overcoming the 'opaqueness' of moral decision-making;
c. Multiplicity of viewpoints – taking into account the multiplicity/plurality of known ethical viewpoints;
d. Exposition of case-relevant ethically relevant aspects – taking into consideration all ethically relevant aspects of the issue, including the factual information that potentially contributes to strengthening or weakening a particular outcome or judgment;
e. Inclusion of ethical arguments – understanding the arguments behind a particular decision, in order to enable rational critique and debate.

At this point, it is worth mentioning the basic assumptions that underlie the design of our proposed framework: i) the need to be sufficiently comprehensive in order to capture the different perspectives on geoengineering and allow access to all relevant facts and normative considerations that lie behind a particular position; ii) the need to identify the salient ethical concerns according to which the social and ethical impacts of geoengineering can be assessed; iii) the possibility of subjecting the conflicting moral accounts to rigorous examination in the light of agreed ethical principles; and, last but not least, iv) the need to provide substance for ethical deliberation, so as to help decision-makers reach sound judgments and responsible decisions about the ethical acceptability of geoengineering research and deployment.

Thus, building upon previous efforts to identify an appropriate tool for rational ethical analysis, we suggest considering (with the necessary adaptations) the approach developed by Prof. Ben Mepham and his colleagues at the University of Nottingham in the early 1990s for translating some of the criteria of 'ethically sound frameworks' into a procedural and substantive tool [6] – the Ethical Matrix.

The Ethical Matrix (EM) was initially designed to facilitate ethical deliberation by those with particular knowledge and/or interest in agri-food biotechnologies (Mepham 1996, 2000). Since then, the matrix has gained popularity and attracted considerable attention from specialists in different fields. In recent years, it has been developed further to facilitate ethical deliberation around the introduction of novel technologies into society and to help decision-makers arrive at sound judgments and defensible decisions about the ethical acceptability and/or optimal regulatory controls for existing or prospective technologies (Kaiser et al. 2007; Mepham 2010; Cotton 2009; Jensen et al. 2011; Forsberg 2007).

As an ethical tool, the EM should not be confused with a particular ethical theory – which, ideally, '*would distinguish all morally right from all morally wrong or morally neutral actions'* (Kaiser et al. 2007, 67). As emphasised by Cotton, the EM '*is intended as a tool for mapping out the issues underpinning a decision, rather than determining an ethical decision using some metric of evaluation*' (Cotton 2009, 160). The EM should be seen as a practical and pragmatic tool

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[6] '*By bringing ethical considerations to the fore, it acts as a substantive ethical tool; and by requiring policy-makers to articulate their assessments of impacts on each cell of the matrix, it acts as a procedural tool'* (Mepham 2010, p. 25).

designed to facilitate explicit ethical decision-making, without necessarily implying a unique normative answer to all issues (Kaiser et al. 2007). Accordingly, the ethical soundness of an EM relies on its capacity to take into account all information that is crucial to assess the multiplicity of normative viewpoints, ensuring that the ethical components of the approach are translated into terms which are meaningful to the different interest groups, and that their normative reasoning is transparent to all external reviewers and evaluators.

The ethical matrix uses a 'principled' approach to ethics. In line with the approach developed by Beauchamp and Childress in the field of biomedical ethics, it appeals to a set of *prima facie* principles (i.e. rules of action that are 'valid at first appearance'). Hence, the three basic principles employed in the EM were chosen to represent the major traditional ethical theories, namely: i) respect for wellbeing, representing the major utilitarian principle; ii) respect for autonomy, representing the major deontological principle; and iii) fairness, representing respect for justice (Rawls 1951, 1972), which is derived from both utilitarian and deontological theories (Mepham 2005).

It should be noted that, in the EMs that have been applied to assess the ethical impacts of biotechnologies in the fields of agriculture and food technology, 'respect for wellbeing' combines the principles of 'beneficence' and 'non-maleficence' (to which Beauchamp and Childress refer as separate ideas) – partly because it simplifies the framework, but also because in the context of agri-food biotechnologies the two principles are inextricably linked (Mepham 1996, 2000). However, as Mepham also emphasises, in some circumstances (as we believe to be the case in geoengineering), it might be preferable to retain the original distinction between these two utilitarian principles (Mepham 2000). Indeed, as the controversy around the 'lesser evil' argument[7] suggests (Gardiner 2010; Rickels et al. 2011; Corner and Pidgeon 2010; Gardiner 2011; Hamilton 2011), the difference between the principle of non-maleficence (a norm of avoiding the causation of harm) and the principle of beneficence (a group of norms for providing benefits and balancing benefits against risks and costs) seems to be fundamental to interpreting the various assumptions and normative claims in this area of debate.

In any case, the three (or four) *prima facie* principles together represent what is referred to as 'common morality', i.e. '*moral norms that bind all persons in all places*' (Beauchamp and Childress 2001, 3), and their inclusion in the framework acknowledges the plurality of perspectives that might be brought to an ethical analysis (Mepham 2010). As we can see in Table 1, this ethical component of the method forms the columns of the EM.

The second component of the method, listed in rows, consists of a set of selected interest groups or parties affected by the issue in question. These might include different groups of people, such as consumers and food producers, but also non-humans, such as farm animals or the environment (Food Ethical Council n.d.). The question of which interest groups are included in the EM depends heavily on the issue at hand.

In the case of geoengineering, the list of potentially affected interest groups is broad (including most nations, subnational groups, nongovernmental organisations, corporations and civil societies). Thus, and because '*the global impacts of geoengineering activities – both its benefits and risks – may be unevenly distributed across stakeholders*' (Bracmort and Lattanzio 2013, 21), we suggest that the best way to capture the explicit listing of stakeholders' viewpoints is to consider the large spectrum of possible government programmes for sustainability that the concept of Earth system governmentality encompasses. Accordingly, the first and last rows of Table 1 depict the extremes of this continuum, i.e. the two types of government programme for sustainability ('management first' and 'ethics first') that occupy the end-points of the Anthropocene imagery (Lovbrand, Stripple, and Wiman 2009).

The 'management first' approach '*draws upon the optimistic view of human control and self-determination embedded in Earth System thinking and focuses on options and caveats for*

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[7] The core lesser-evil argument can be summarised as follows: '*We could end up in a future situation (i.e., when climate sensitivity is very high or if our efforts to reduce emissions are insufficient) in which the (admittedly high risk) deployment of CE technology represents the lesser of two evils*' (Rickels et al. 2011, p. 27).

technological fixes and geoengineering' (Idem). The first row of the EM (structured around established ethical theories) sets out the main arguments that have been advanced under this approach in the geoengineering debate, which, together, tend to sustain the idea that 'we need to go further and faster in researching and deploying these technologies'.

The counterpoint of this extreme interpretation of the Anthropocene is set out in the last row of the EM, which represents the 'ethics first' approach – '*humbled by the scale, complexity and vulnerability of the Earth System, this political programme highlights the need for a new ethical framework for Earth stewardship*' (Idem). Accordingly, this lists the main arguments that have been advanced against geoengineering research and deployment - direct justification of a research ban and an international moratorium on deployment (Rickels et al. 2011).

The outline of this framework underlines the importance of facilitating deliberative assessments in order to map the plurality of perspectives and explore qualitative aspects of uncertainty in and around geoengineering. Thus, the empty spaces between these two extreme end-points of the Anthropocene imagery reflect the scope for democratic decision-making and public engagement in the field of geoengineering. In fact, in the context of current 'policy vacuums', characterised by '*a growing sense of urgency coupled with a lack of knowledge of what to do and a lack of institutions where the issues could be addressed'* (Rommetveit, Funtowicz, and Strand 2010), the recurrent claims that argue for a closer connection between science and society, with the purpose of exposing to public scrutiny the hidden assumptions, values and visions that are deeply embedded in science and technology, seem more than justified. Moreover, as pointed out by Bucchi and Neresini, '*public participation warrants attention not only because it may be a solution to a decisional impasse on technoscience issues or to a crisis of representativeness, but also because it exposes the inevitably political nature of current dilemmas*' (Bucchi and Neresini 2008, 466). Indeed, it is here, in the realm of the controversies over science and technology, that new assemblages are being created and new alliances for democratic regeneration and revival are being forged (Irwin and Michael 2003).

			GEOENGINEERING RESEARCH			
			Beneficence	**Non-maleficence**	**Autonomy**	**Fairness/Justice**
EARTH SYSTEM GOVERNMENTALITY	End point of the spectrum	'Management first approach'	**Innovation argument:** R&D in geoengineering triggers spin-offs and creates jobs.	**Side-effects of R&D are negligible:** The side-effects of geoengineering research should be negligible.	**R&D first argument:** R&D should not be constrained; once technologies have been developed, a decision can be taken as to their implementation.	**Argument from survival:** Without technical counterbalances, climate change might endanger the survival of the entire human species.
		(...)	(...)	(...)	(...)	(...)
	End point of the spectrum	'Ethics first approach'	**Hubris argument:** Geoengineering belongs to a tradition of large-scale interventions which have ignored the boundaries of technical manipulation. It testifies to arrogance and a form of self-deceit that will heavily backfire.	**Moral hazard argument:** Even mere research into geoengineering and the vague prospect of a technical solution to the climate problem could deter governments and private stakeholders from carrying out mitigation measures.	**No informed consent:** Geoengineering should be researched and carried out only with the broad and well-informed consent of everyone involved.	**Risk transfer argument:** By carrying out research into and planning for geoengineering, one passes on risks to future generations.

			GEOENGINEERING DEPLOYMENT			
			Beneficence	**Non-maleficence**	**Autonomy**	**Fairness/Justice**
EARTH SYSTEM GOVERNMENTALITY	End point of the spectrum	'Management first approach'	**Lesser-evil argument:** At some future point in time, the deployment of geoengineering methods could be the lesser of two evils, and we should prepare for that situation.	**Easiness argument:** Geoengineering allows dangerous climate change to be bypassed without altering lifestyles, habits and the basic structure of our economy.	**Do-it-alone argument:** Geoengineering can be carried out by a small group of countries — without the long-term cooperation of all nations — for the good of all humanity.	**Compensation:** For the purposes of compensation, intentional intervention is required.
		(…)	(…)	(…)	(…)	(…)
	End point of the spectrum	'Ethics first approach'	**Catastrophic side-effects:** The catastrophic side-effects of geoengineering are not the lesser evil.	**Intentional harm:** Deploying geoengineering involves harming some people (rather than others); this reduces the ethical value of our lives.	**Human rights:** Geoengineering deployment alters the global institutional and economic conditions so that human rights will be ensured to a lesser degree.	**Distributional effects**: The uneven distribution of climate impact offsets (benefits), costs and harmful side-effects associated with geoengineering deployment is unjust.

Table 1 - The ethical matrix revisited: towards an analytical framework for evaluating the ethical dimensions of geoengineering research and deployment.

Sources used to assemble these arguments: (Rickels et al. 2011; Betz and Cacean 2012, 2011).

Geoengineering at the Centre of an Epochal Break in Scientific History

In the previous section, we proposed an adaptation of the ethical matrix devised by Mepham (Mepham 2000, 2004; Mepham et al. 2006) in order to: i) identify and map the plurality of perspectives on geoengineering across the wide spectrum of possible government programmes for sustainability; ii) structure the conflicting moral accounts and crucial ethical concerns over geoengineering around the major traditional ethical theories; iii) make explicit the value judgments about the attempts to 'act into nature' that are embedded in geoengineering proposals; and lastly iv) facilitate ethical deliberation and assist ethical decision-making in this field.

As the outline of our framework suggests, there is indeed a need for public engagement and democratic decision-making in the area of geoengineering. Although this idea is not new (Jamieson 1996), only recently have the practical implications and challenges of such demands begun to be properly considered. In this context, many authors have been arguing about the importance of considering public perceptions of geoengineering (Boyd 2008; Bracmort, and Lattanzio 2013; Cicerone 2006; Miller 2010a; Miller 2010b; Morton 2007; Powell et al. 2010; Royal Society 2009; Rayner et al. 2013). What seems to be at stake is not only the need to identify the ethical issues embodied in citizens' concerns, but also to shed more light on the wider social values, interests and imaginations around science and technology.

As we have argued elsewhere (Curvelo and Pereira, forthcoming), the full meaning of geoengineering proposals can only be grasped in the context of the wider 'imaginaries' of science and technology in which geoengineering narratives are rooted. Hence, it is suggested that those imaginaries, and the master-narratives that sustain them, should be examined further, particularly by considering alternative ethical paradigms, such as discursive or deliberative ethics (Habermas 1992, 1993).

Therefore, in supporting the need to subject the scientific debate on geoengineering to more open and critical reflection, we highlight the importance of rebuilding the 'geoengineering scientific worldview' on social processes of trust and credibility (Irwin and Wynne 1996), in this way impelling climate change science to reveal more clearly the competing interests, values and assumptions underlying geoengineering proposals. We also see this as an opportunity to promote critical thinking about social problems that tend to be 'circumvented' and reduced to technological fixes, thus 'alienating' and 'diverting' our attention from an essential question, that of our place in nature.

Because the new system of global environmental science seems to imply a profound reorientation of the scientific enterprise, we also suggest that key research questions concerning the ontological, epistemological and normative dimensions of geoengineering can be better addressed from a perspective that takes into account the social and technoscientific discontinuities which have shaped the interactions between socioeconomic, technological and environmental systems. Indeed, it is only in the light of a perceived major shift in the representational practices of science that the very nature of geoengineering can come into question.

> 'If one wishes to draw a distinctive line between the modern age and the world we have come to live in, he may well find it in the difference between a science which looks upon nature from a universal standpoint and thus acquires complete mastery over her, on one hand, and a truly "universal" science, on the other, which imports cosmic processes into nature even at the obvious risk of destroying her and, with her, man's mastership over her' (Arendt 1958, 268).

It is precisely here that we understand the relevance (and the necessity) of considering our second 'epochal break', '*the idea that there has been a transformation in the relation of science, technology, and society so profound that our received notions of "science" have been superseded by something else … the epochal shift from the scientific enterprise to the regime of technoscience*' (Nordmann, Radder, and Schiemann 2011).

From this perspective, one possible way of looking at the geoengineering issue and the ‘scalar dislocations’ that it introduces into modern systems of experience and understanding is to explore the differences and affinities between intentional climate change proposals and many other technologies that have emerged in the recent past. The idea of terraforming, which once informed dreams about exploring and exploiting other planets (Fogg 1995), seems to have been reinvented under the aegis of Earth system science to re-centre on Earth itself the proposals for the wholesale rearrangement of a planet’s environment to support human life. Like space exploration in the 1970s and 1980s, geoengineering proposals challenge the basic concept of limits that underpins the environmental movement and hold out new prospects for enhancing and expanding our current lifestyles.

By drawing attention to recent efforts to identify the right vantage point from which to address the epoch-making transition from the scientific enterprise to the regime of technoscience, we also highlight the relevance of exploring the technoscientific objects of geoengineering in order to scrutinise the ‘experimental’ and ‘upstream’ nature of geoengineering proposals. Indeed, the ‘pressure of practice’ under which science operates today (Carrier 2011) is giving rise to the emergence of new objects of research – ambivalent beings, hybrid products and theoretically constructed objects through which we gain a new understanding and control of nature – that call for a more careful consideration of the complex narratives and practices of science and technology (Funtowicz and Ravetz 1993, 1994b, 1994a; Latour 1987; Haraway 1997; Law 2002; Michael 2006). Consequently, some authors have suggested that it is precisely at the level of these objects of research that we can find the meaningful distinction between science and technoscience, an ontological difference that ‘*becomes more explicit when research results are presented in particular settings and when the objects of research are exhibited for the specific interest they hold*’ (Bensaude-Vincent et al. 2011, 365). Accordingly, and by way of illustration, one could say that when the result of a global climate model experiment is presented as scientific evidence for understanding the importance of aerosols forcing on the climate system, this would agree with traditional conceptions of science. However, when sulphate aerosols are presented for their capacity to counteract the climate forcing of growing CO_2 emissions, this should be seen as a ‘hallmark of technoscience’.

On the other hand, and because geoengineering proposals fall into a specific class of scientific endeavour, in which the object of interest is not modular and encapsulated (Bunzl 2009), its underlying concept of experimentation points to a profound reorientation of technoscientific practices in contemporary societies, in what has been seen as a major shift from the ‘laboratory ideal’ to the ‘field ideal of experimentation’:

> ‘The laboratory ideal involves designing manipulated, well-controlled, isolated experimental systems; the field ideal acknowledges their complexity, blurred boundaries, and unpredictable response to interventions. Field experiments could hardly be called an alternative ideal if they had not undergone a reevaluation in the philosophy of science and a reassessment with regard to their social relevance. We suggest that both changes can be observed especially well in the 1980s in the domain of the environmental sciences. Even if field experiments were not entirely new at that time, environmental concerns in science and society gave them a new cognitive status, institutional backing, and a specific rhetorical image. Today we are seeing the spread of new styles of experimentation to many areas of society. Experiments performed in *open spaces* might be, say, a social reform or a medical treatment, an ecological remediation or a technological innovation’ (Schwarz and Krohn 2011, p.120).

These are but a few examples of alternative ways of interrogating geoengineering, which, in the context of this epochal break, may ultimately be seen as an illustrative metaphor of particular technoscientific promises and ‘technofix’ narratives that are emerging in our society.

Final Remarks

Different conceptions, understandings and value assumptions concerning the changing relationships between science and society, science and technology, and science and nature tend to shape the geoengineering debate and inform the analytical framework within which the geoengineering domain has been problematised. This reinforces the need to unbind geoengineering discourses from the deeply embedded narratives of science, technology and society that present technoscientific innovation as the solution to our most critical problems and as a substitute for social change (Felt et al. 2007). Similarly, the construction of narratives that give meaning to human action within nature, and provide guidance for humans' domination of nature, deserves a more critical and open reflection than has been the case to date. Looking at geoengineering with more distance and detachment presupposes taking a broad, long-term perspective, in terms both of the human-environment relationship and the relationships between science, technology and society.

In this paper, we have presented and analysed two different frameworks within which to address the ethical issues in geoengineering. The first represents the mainstream Earth system science perspective, while the second corresponds to an alternative view from the field of social studies of science and technology. Central to both is the concept of an 'epochal break', in the former in terms of the human-earth relationship, in the latter in terms of the relationship between science, technology and society.

As we have suggested, these two epochal breaks reinforce the substantive and procedural roles of the proposed adapted version of the ethical matrix. By considering the concept of 'Earth system governmentality', and the range of practices that have produced the 'coupled human and ecological system' as a thinkable and governable domain, we argue that the continuum of possible government programmes for sustainability that the Anthropocene imagery entails might bring the crucial ethical considerations in and around geoengineering to the fore. This is expected to lead to a more conscious and explicit articulation of the interplay between factual judgements and value judgements, thus helping decision-makers reach sound decisions about the ethical acceptability of geoengineering proposals.

On the other hand, the positioning of geoengineering within the second epochal break is considered critical to open up the debate and encourage further reflection on the very nature of geoengineering and its framing assumptions. Ultimately, it is hoped that this perspective will stimulate the ability of decision-makers to reason critically about alternative courses of action, and might inspire a vision of human enlightenment that goes far beyond the idea of mastery and control over nature to incorporate a proper balance of epistemic humility and epistemic hope, thus providing a cautious approach to action.

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Imag[in]ing geoengineering – the plausible and the implausible

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Abstract: The universe of geoengineering is filled with all sorts of imageries. They are all part of the geoengineering story, revealing facts, knowledge, values, fears, desires, promises, anxieties, incredulity, about not only the idea of deliberately manipulating Earth's climate to offset anthropogenic climate change, but also, and above all, what we know about the world and how we make sense of our place in it. In this context, where geoengineering can be seen as an illustrative metaphor of particular technological promises and 'upstream solutions' of modern technoscientific societies, we stress the relevance of considering the continuum between imaging and imagining (imag[in]ing) in order to examine the plausibility of current geoengineering proposals. By suggesting that the visual representations of geoengineering should be seen as pictorial narratives, we draw on Walter Fisher's homo narrans metaphor. Thus, adopting the concept of 'narrative rationality', we propose to analyse the sense-making structures of a set of selected visual narratives of geoengineering and test them against the principles of narrative probability and narrative fidelity.

Keywords: geoengineering; climate engineering; plausibility; plausible reasoning; narrative rationality; imag[in]ing.

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1 Introduction

Since the adoption of the United Nations Framework Convention on Climate Change (UNFCCC), responses to address climate change have until recently fallen essentially within two major groups of strategies, namely:

1 mitigation measures, which comprise all human interventions to reduce the anthropogenic forcing of the climate system, such as reducing greenhouse gas sources and emissions and enhancing greenhouse gas sinks

2 adaptation measures, which include any adjustments made to natural or human systems in response to actual or expected impacts of climate change, with the aim of moderating harm or exploiting beneficial opportunities.

However, another strategy to limit the impacts and consequences of climate change has been gaining ground over the past decade: the idea of geoengineering, commonly defined as the "deliberate large-scale manipulation of the planetary environment to counteract anthropogenic climate change" (Royal Society of London, 2009).

Hitherto, the scientific community has regarded geoengineering proposals with scepticism, if not outright disbelief (Cicerone, 2006; Fleming, 2010; Wolpert, 2008). Indeed, in 2007 the Intergovernmental Panel on Climate Change (IPCC, 2007) still considered that "geo-engineering options, such as ocean fertilisation to remove CO_2 directly from the atmosphere, or blocking sunlight by bringing material into the upper atmosphere, remain largely speculative and unproven, and with the risk of unknown side-effects". Nonetheless, during the last few years something appears to have changed, for the IPCC (2012) is now considering "the role of geoengineering within the portfolio of response options to anthropogenic climate change".

This recent 'political-epistemic'[1] movement towards a more plausible geoengineered world is illustrated by the way the scientific and policy communities are beginning to seriously consider geoengineering as a potential strategy for addressing climate change and by the general perception that this topic will remain on the climate change agenda for years to come. Some significant events contributed to this: the publication in 2003 of two high profile reports by the US National Research Council (2003) and the US Pentagon (Schwartz and Randall, 2003) recommending further research into geoengineering, and, perhaps most significantly, the 2006 editorial essay of the journal *Climatic Change*, in which Nobel laureate Paul Crutzen called for active scientific research into geoengineering schemes that aim to enhance the Earth's albedo by releasing sulphate aerosols into the stratosphere (Crutzen, 2006). But to better understand why "geoengineering has been transformed from a topic discussed largely in science fiction and esoteric scientific papers into mainstream scientific and policy debate" (Macnaghten and Szerszynski, 2013) it is important to place these events in the context of increasing doubt and disbelief regarding the commitment of the international community to adequately respond to the problem of global warming.

In fact, throughout the 21st century, the geoengineering debate has been closely coupled with the climate change agenda, being affected by its major convulsions in the scientific and political arenas. The grossly unsuccessful efforts to lower carbon dioxide emissions (Crutzen, 2006) – a symptom of what has been described as a "problem of political inertia" (Gardiner, 2010) – the resonant call for greater planetary management and Earth system control (Steffen and Tyson, 2001), and the tendency to favour transformational rather than incremental responses to climate change (New et al., 2010) are all factors that may help explain why the scepticism and suspicion with which geoengineering was greeted is now giving way to a more pragmatic and serious consideration of its latest scientific and technological breakthroughs and the challenges ahead.

But how plausible are current geoengineering proposals? Is the plausibility of geoengineering due to the recent developments in the field, or is the broader context within which those developments are taking place the key element in understanding this shift? What are the determinants of geoengineering plausibility?

In order to address these questions, we will focus our analysis in this paper on the visual representations of geoengineering. The rationale behind this approach is twofold. First, by acknowledging that the visual modes of representation (that are integral to many kinds of thinking) function as a powerful method of meaning making, and that pictorial expressions are not qualitatively different from verbal expressions (Barbatsis, 2005), it seems opportune to draw attention to the concept of 'narrative rationality' (Fisher, 1987, 1985) and to the continuum between imaging and imagining ('imag[in]ing') (Ruivenkamp and Rip, 2011) in order to explore the way geoengineering images convey plausible, or implausible, arguments about current proposals to intentionally modify the global climate and how a *geoengineered world* could be. The second assumption underlying this approach is that the pictorial representations of geoengineering can also provide valuable insights into its objects of research, an issue that has not received a great deal of attention but seems particularly relevant when considering the plausibility of geoengineering proposals.

2 Questioning the plausibility of geoengineering

Why question the plausibility of geoengineering? Given the current state of affairs, in which geoengineering is receiving increasing consideration from academics and policy analysts as a possible means by which to offset human-induced climate change, this might seem a rather elementary or needless question. Yet, given the conflicting arguments and the variety of theses that inform the current debates on geoengineering, we are compelled to acknowledge that not only the need to address this question should be taken more seriously, but also that answering it is inevitably far from straightforward.

> "The current debate on climate engineering is far more complex and multilayered than a purely scientific-economic analysis would indicate. To understand the complexity of the debate, it is necessary to collect, structure, and interrelate the wide range of arguments advanced in favor of or against climate engineering. (…) As the analysis reveals, individual arguments can frequently only be assessed for validity and plausibility when different disciplines are taken into account." [Rickels et al., (2011), p.14]

Indeed, although plausible reasoning seems to play an important role in the ongoing debates on geoengineering, there is still a lack of understanding of how this "practical epistemic device" (Rescher, 2009) is being used within the context of the disputed arguments and controversial theses on the pros and cons of geoengineering research and deployment.

While some authors emphasise the plausible assumptions supporting the need for further and more in depth research into the field of geoengineering – be it to increase our ability to access this topic, or ultimately, to deploy (in case of a climate emergency) the associated technologies (Royal Society of London, 2009; Hemming and Hagler, 2011; Morris, 2008; Wold et al., 2009) – others draw attention to the highly inconsistent and implausible features that dominate the geoengineering debate (Macnaghten and Szerszynski, 2013; Thernstrom, 2010; Curry, 2011). Moreover, even a cursory glance at the literature on the subject reveals the diversity of contexts in which the concept of plausibility has been invoked, such as those related with:

1. the description, or formulation, of the conditions that justify acknowledging the arguments in favour of research into and possible deployment of geoengineering (Keith, 2010)
2. the attempts to bring into prominence the epistemic and non-epistemic values attached to geoengineering proposals (Gardiner, 2011a)
3. the disentanglement of the kinds of world that geoengineering might bring into being (Macnaghten and Szerszynski, 2013)
4. the critical exploration of the assumptions that underpin governance debates around these technologies (Keith et al., 2010b; Bodansky, 2012)
5. the discussion about the underlying assumptions of technical and economical assessments conducted in this field (Bellamy et al., 2012).

Against this background, the development of new research initiatives on geoengineering, the exponential increase of media and scientific publications devoted to the topic, and the growing number of policy reports released over the past few years not only point to the ever more plausible role that solar radiation management (SRM) and carbon dioxide removal (CDR) methods are likely to play in the portfolio of solutions to address climate change, but also bring to light threatening situations of cognitive dissonance and/or inconsistencies connected with the complex arguments that characterise the geoengineering debate (Rickels et al., 2011). In fact, because "all approaches to geoengineering express an implied ontology (an embedded theory of who we are, how we are situated in the realm of being) and a presumed ethics (an embedded theory of how we ought to behave)" (Weiskel, 2012), the very different arguments that have been advanced for and against geoengineering reveal the rather complicated and entangled relationships between 'is' and 'ought', facts and values, descriptive and normative, epistemic and material.

> "On the one hand, the arguments make use of empirical assumptions which can be assessed scientifically. On the other hand, they always rely on more or less far-reaching normative premises, as well. Such normative assumptions may involve the weighting of side-effects or the moral assessment of inequalities; in any case, they evade an empirical, scientific evaluation." [Rickels et al., (2011), p.32]

As the comprehensive study commissioned by the German Federal Ministry of Education and Research refers, the arguments that have been advanced in the current debate on geoengineering confront us with qualitatively different sets of assumptions. Because these assumptions are associated with distinctly different kinds of reasoning, a closer examination of the geoengineering debate should begin by trying to understand how empirical and normative assumptions are supported by the reasons offered to back them up.

In the field of geoengineering, where knowledge is incomplete, uncertain, and inconsistent, the inductive and deductive arguments that one would expect to encounter in the scientific model of justification – the positivistic model of scientific verification of empirical and analytic propositions – seem to intermingle with a third class of arguments, the so-called abductive, presumptive, or plausibilistic forms of argumentation. This class of arguments is based on a kind of plausible reasoning that combines normative or value stating premises (premises stating general rules) with premises drawn from the presumed facts of a case (Walton, 2003) – be it a simulation model that seeks to address the climatic consequences of geoengineering proposals (Matthews and Caldeira, 2007; Lenton and Vaughan, 2009), a limited and controlled real world geoengineering experiment (Pidgeon et al., 2013), or an assessment of different geoengineering techniques in terms of efficiency, affordability, safety, controllability, timeliness, or reversibility (Royal Society of London, 2009; Vaughan and Lenton, 2011; Boyd, 2008).

Indeed, the contexts in which the concept of plausibility has been used and the set of things it refers to not only reveal "a very large class of plausibility reckonings deeply embedded in actual cognitive practice" (Gabbay and Woods, 2005a), but also expose the dual nature of plausibility in hypothetical reasoning:

> "Plausibility trisects reasoning in characteristic ways. We can conceive of the plausible *as that which is reasoned from* and *as that which is reasoned to*. We can also see it as characterizing the inference link between *what is reasoned from* and *what is reasoned to*. Seen this way, a piece of reasoning may have premisses that are plausible; it may have a plausible proposition as its conclusion; and its conclusion may be plausibly inferred from its premisses. It is also notable that plausibility is ambiguous as between propositions and what we might call the "engagement of propositions". The two are logically independent. Planck famously thought that his quantum hypothesis was radically implausible, but he conjectured it all the same, illustrating that it can sometimes be reasonable to accept (if only tentatively) the unreasonable. Given the linguistic tie between the reasonable and the plausible, a like concurrence affects the plausible. *Accordingly we shall distinguish propositional plausibility from strategic plausibility*." [Gabbay and Woods, (2005b), p.68; emphasis added]

This distinction points to the ambiguous cognitive and epistemic status of plausibility and highlights the importance of considering both the explanatory and instrumental aspects of abductive reasoning (Magnani, 2009) in the context of the geoengineering debate, where the two different kinds of plausible contentions (propositional and strategic plausibility) are being brought into play to answer two very different kinds of questions: *what is it reasonable to believe?* and *what is it reasonable to do?*

According to Hodgson, these two questions involve the type of decisions that "cannot be made by overt calculation or computation or any other way involving the overt mechanical application of conclusive rules" (Hodgson, 2012). As he argues, these are rather the typical questions that can only be answered by the exercise of reasonable (albeit fallible) judgment. In fact, the need to engage in this kind of (inconclusive) plausible reasoning cannot be eliminated by the ability to use the logical structure of scientific knowledge – or what Fisher (1987) refers to as the *logic of reasons* associated with the *rational world paradigm*. As suggested in the following section, in this sort of situation – when we are confronted with these kinds of questions, when we need to make judgments on the basis of inconclusive reasons, and when we need to transform the logic of reasons into a logic of good reasons – the narrative paradigm offers a means of transcending the "uncompromising and irreducible oppositions presented by all kinds of absolutisms: dualisms of reason and imagination, of knowledge and opinion, of irrefutable self-evidence and deceptive will, of a universally accepted objectivity and an uncommunicable subjectivity, of a reality binding on everybody and values that are purely individual" (Perelman and Olbrechts-Tyteca, 1969).

This goes some way towards recapturing the Aristotelian question of balancing instrumental rationality with value-rationality (Flyvbjerg, 2001, 2004). Accordingly, when analysing the various qualities of plausible claims deemed important in the field of geoengineering, we stress the relevance of considering the neo-Aristotelian accounts of practical reasoning that, rooted in a critique of modern instrumental technical rationality, seek to redress the imbalance between the intellectual virtues of *episteme*, *techne* and *phronesis* (Flyvbjerg, 2001).

With this background in mind, we argue that the considerations of reasonability and plausibility that lie at the heart of the geoengineering debate should be understood as manifestations of a reasoning process in between two theoretical traditions, namely:

1. the instrumental technical rationality of modern conceptions of scientific reasoning (the epistemological stance engendered by enlightenment rationalism and logical positivism)
2. the tradition of practical reasoning that draws on practical value rationality to challenge the logical empiricism, its ontological privileging of scientific knowledge, and the adequacy of instrumental rationality alone.

As we will see in the following sections, these kinds of considerations are also embedded in the pictorial narratives of geoengineering, with their implied reasoning corresponding in many ways to a form of narrative rationality pertaining to rhetorical action.

3 Exploring geoengineering plausibility through expanded notions of narrative

Different conceptions, understandings, and value assumptions concerning the changing relationships between science and society, science and technology, and science and nature tend to inform the geoengineering debate and sustain a variety of discursive frames that shape the way geoengineering has been problematised (Scholte et al., 2013; Sikka, 2012; Huttunen and Hildén, 2013; Luokkanen et al., 2013; Nerlich and Jaspal, 2012). This reinforces the need to unbind geoengineering discourses from the deeply embedded narratives of science, technology, and society that present technoscientific innovation as the solution to our most critical problems and as a substitute for social change. Similarly, the construction of narratives that give meaning to human action within nature, and provide guidance for humans' domination of nature, deserves a more critical and open reflection than has been the case to date.

Accordingly, one possible way of looking at the geoengineering issue and the scalar dislocations that it introduces into modern systems of experience and understanding is to explore the plausibility of geoengineering by adopting expanded notions of narrative that account for its particular ways of rendering the world in both visual and verbal forms. Thus, by assuming that pictorial expressions are not qualitatively different from verbal expressions (Barbatsis, 2005), we propose to analyse some visual representations of geoengineering in order to understand how they use a narrative way of structuring thought to make sense of a *geoengineerd world*. In doing so, we draw on Fisher's *homo narrans* metaphor, suggesting that both the descriptive and explanatory elements of the visual narratives of geoengineering need to be examined to understand the role specific plausibility structures play in satisfying the demands of probability and fidelity of those narratives.

The descriptive and explanatory elements of a narrative point towards the two different kinds of narrative research described by Polkinghorne: the descriptive narrative research aims “to render the narrative accounts already in place which are used by individuals or groups as their means for ordering and making temporal events meaningful”; the explanatory narrative research seeks “to construct a narrative account explaining ‘why’ a situation or event involving human actions has happened” [Polkinghorne, (1988), p.161]. We expect that the first kind of narrative research may help us to articulate the various (conflicting?) narrative schemes that lie underneath the visual representations of geoengineering – narrative schemes that operate not only in the realm of rationality, knowledge, and facts, but also in the realm of subjectivity, values, imagination, and fiction. However, it is only within an explanatory narrative approach that we will be able to address the fundamental question of why geoengineering is gaining more serious consideration and becoming an increasingly plausible solution to climate change. Because explanatory narrative research is retrospective and retrodictive[2], adopting this kind of approach does not seem an easy task when considering the ongoing debates on geoengineering. Nonetheless, because an analogy can be made with prior, already-told stories – of which “the pathological history of weather and climate modification” is just one example (Fleming, 2010) –, we believe this task is not only possible, but also an imperative:

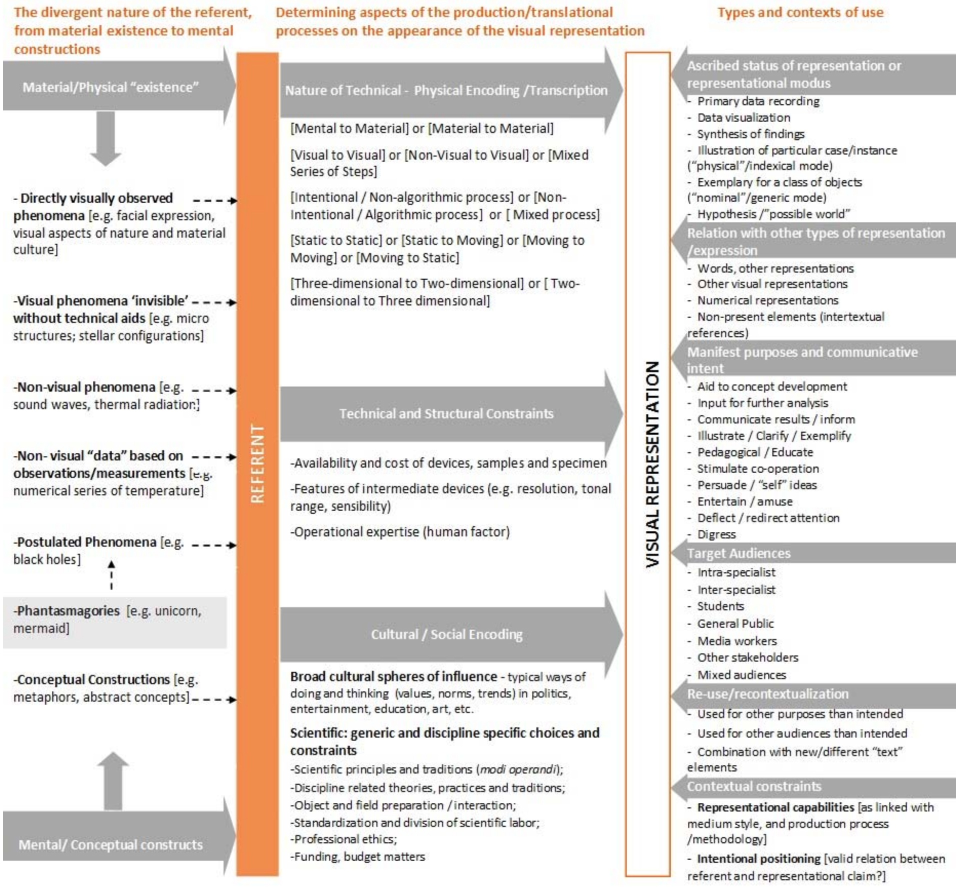
> “I can only answer the question ‘What am I to do?’ if I can answer the prior question ‘Of what story or stories do I find myself a part?’ We enter human society, that is, with one or more imputed characters – roles into which we have been drafted – and we have to learn what they are in order to be able to understand how others respond to us and how our responses to them are apt to be construed.” [MacIntyre, (1984), p.216]

In addition, we must confront the resistance put up by science to this kind of investigation. In fact, explanatory narrative research is not typically used in the sciences, partly because “narrative truth is distinguished from other kinds of formal science truths by its emphasis on the life-like, intelligible and plausible story. Stories typically reflect a coherence (as opposed to correspondence) theory of truth in that the narrator strives for narrative probability – a story that makes sense; narrative fidelity – a story consistent with past experiences or other stories; and aesthetic finality – a story with satisfactory closure and representational appeal” [Sandelowski, (1991), pp.164–165].

In the context of this discussion, which points to some of the presuppositions that underpin Fisher’s narrative paradigm, it is important to emphasise the difference between the elements of narrative theory, a theoretical distinction stressed by structuralists who considered that each narrative has two parts: a story (what is depicted in a narrative) and the discourse (how it is depicted). According to Chatman (1978, pp.19–22), the story consists of the content or chain of events and the existents (characters and items of setting), while the discourse refers to the means by which the content is communicated, thus comprising two subcomponents: the narrative form itself (the structure of narrative transmission) and its manifestation (its appearance in a specific materialising medium). In order to capture all elements of the communicative situation, Chatman reminds us that narrative is a semiotic structure, which presupposes that it should include a form and a substance of expression and a form and a substance of content.

Moreover, the broad amplitude of intended or unintended choices that may influence visual representation is a fundamental aspect to which a visual analyst should be alert. This broad amplitude of the representational space – in what Pauwels (2006) refers to as the *visual representational latitude* – is determined by the nature of the problem being depicted (type of referent), by the intentional and unintentional choices of the author (the context of production), and also by the characteristics of the audience in relation to a particular visual representation (the context of use) – Figure 1.

Figure 1 A conceptual framework for analysing and producing visual representations in science (see online version for colours)



Source: Adapted from Pauwels (2006, p.23)

4 From geoengineering imag[in]ing to geoengineering plausibility

Focusing on nanotechnology representations, Ruivenkamp and Rip (2011, p.185) mention that it is "the entanglement between imaging and imagining which is the key to understanding what images do". While imaging refers to the creation of images based on data, aiming for resemblance and offering 'a view on what is out there', imagining refers to the creation of impressions, offering visions of worlds that might be realised. Thereby, the word 'imag(in)ing' aims at capturing the continuum between imaging and imagining, referring to something that has not only to do with the way an image may bear some resemblance to that which it represents, but also with the way it might 'stands for' and is able to 'act for'. It thus refers to the realm of symbolic action, in the sense that these visual representations have sequence and meaning for those who live, create, or interpret them, and might provide a meaning and a rationale for decision and action (Fisher, 1987, 1985).

As in nanotechnology, the images that populate the world of geoengineering tend to balance the past, present, and future in order to communicate the results of recent experiments, as well as to present the potentialities, drawbacks, and risks associated with its associated technologies. Not surprisingly (given what is happening in the field of nanotechnology), the visual representation of geoengineering also involves entangling its present achievements and future visions of what it may become, drawing attention to the anachronism that tends to be associated with innovation processes in the context of knowledge production.

In line with this notion of 'imag(in)ing', we will focus our attention in the following section on the continuum between geoengineering imaging and imagining with a view to exploring the potential of a visual narrative approach for better understanding the plausible and implausible aspects of geoengineering proposals. Thus, also adopting the concept of narrative rationality, we propose to assess the 'narrative fidelity' and the 'narrative probability' of three pictorial narratives of geoengineering.

4.1 How plausible are the objects of geoengineering research?

It seems most reasonable to question the plausibility of geoengineering research in light of its object of interest. Indeed, the pressure of practice under which science operates today (Carrier, 2011) is giving rise to the emergence of new objects of research – ambivalent beings, hybrid products and theoretically constructed objects through which we gain a new understanding and control of nature – that call for a more careful consideration of the complex narratives and practices of science and technology.

Following this appeal, some authors have suggested that it is precisely at the level of these objects of research that we can find a meaningful distinction between science and technoscience, an ontological difference that "becomes more explicit when research results are presented in particular settings and when the objects of research are exhibited for the specific interest they hold" (Bensaude-Vincent et al., 2011). Accordingly, and by way of illustration, it could be said that when the result of a global climate model experiment is presented as scientific evidence for understanding the aerosol climate forcing, this would tally with traditional conceptions of science. However, when sulphate aerosols are presented for their capacity to counteract the climate forcing of growing CO_2 emissions, this should be seen as a 'hallmark of technoscience'.

Thereby, a closer examination of the attempts that have been made to visually represent the objects of geoengineering research may shed some light towards often neglected differences between science and technoscience:

1 in terms of their epistemic ideals and how the corresponding perspectives imply different understandings of the interplay between representing and intervening

2 in terms of their objects of interest and how they hold different functional properties

3 in terms of the guiding ideals or research orientations that tend to shape the practices of science and technoscience in very different ways [*Idem*].

In what follows, we will explore the potential of a visual narrative approach to understanding the role of plausibility in imag(in)ing the objects of interest of geoengineering. We will focus our attention on an image that appeared in an online article entitled 'Engineering a cooler Earth' (Engelhaupt, 2010). In this article Erika Engelhaupt refers to the Asilomar Conference on Climate Intervention Technologies, held in March 2010 in Pacific Grove, California, to describe some of the geoengineering strategies that have been discussed by the scientific community. One of these strategies, which has become known as 'air capture' consists in an industrial process that captures CO_2 from ambient air, producing a pure CO_2 stream for use or disposal (Royal Society of London, 2009). Although not yet tested on a large-scale, several conceptual designs of such air capture units have already been proposed and demonstrated at laboratory scale[3].

The most well-known air capture technology involves the so called 'artificial trees' or 'synthetic trees'. Two terms that suggest the similarity between the engineered air capture process and the way (natural) trees remove CO_2 from the air – because after all, as one of the leading proponents of this technology says: "Every tree demonstrates that capture of carbon dioxide from the air is physically feasible. In addition, technologies that are more effective than trees at scrubbing carbon dioxide out of the air have been developed more than half a century ago" (Lackner, 2008). Furthermore, "filtering machines – think of them as synthetic trees – can capture far more CO_2 than natural trees of a similar size" (Lackner, 2010).

And it is precisely an illustration of an artificial tree, published in the above-mentioned article, which called our attention to the relevance of questioning the plausibility of the technoscientific objects of geoengineering – Figure 2.

Figure 2 Giant air-capture machines, such as artificial trees, could cleanse the atmosphere of excess carbon dioxide (see online version for colours)

Source: Engelhaupt (2010); illustration by Michael Morgenstern (reproduced by kind permission of the author)

Indeed, this image seems to incorporate several elements conveying a sense of plausibility. It gives the idea that the illustrator took into consideration the narrative standards of truth in order to ensure that the story portrayed in this illustration would make sense, would be consistent with past experiences and would provide a satisfactory closure and representational appeal. Everything seems to cohere and hang together: the devices that resemble natural trees and that combine ecological and aesthetical functions; the girl skipping on a rope, suggesting that the environment in which she is playing is safe and healthy and calling attention to the non-disruptive nature of this technology; and lastly, an exuberant sun that seems to have been placed there to remind us that there is nothing to fear about it. Apparently, this picture depicts a story free of contradictions, one that can lay the ground for a more serious consideration of the arguments in favour of research into and possible deployment of this technology. But how plausible is this image? Is it *reasonable to believe* what it says? Is it *reasonable to do* what it suggests?

Although there seems to be "no doubt that air capture technologies could be developed" (Royal Society of London, 2009) and that "it is technically possible to capture CO_2 from air at industrial scale" (Keith et al., 2010a) the plausibility of this image is still questionable. In fact, if we take into consideration the diverse descriptions (Lackner, 2010) and illustrations[4] of artificial tree prototypes we have to recognise that they are far from resembling natural trees:

> "His prototype looks like a big furnace filter, with layers of ruffled leaves of permeable material coated with sodium carbonate. As the air wafts through the filter, the sodium carbonate will combine with the carbon dioxide to become sodium bicarbonate; periodically, a liquid will flush the leaves, washing the bicarbonate into solution. That solution will go to a separator, where electrodialysis will turn it back into carbon dioxide (for sequestration) and sodium carbonate (for reuse in the filter). A unit the size of a forty-foot shipping container standing on the end, says Lackner, would remove a ton of carbon dioxide a day." [Horn and Krupp, (2008), p.241]

This description, although apparently consistent, depicts an unresembling object – something which does not correspond to the devices represented in Figure 2. In this context, one must not forget that "a discourse can be perfectly coherent although it describes a bizarre sequence of events; thus coherence must be evaluated independently of plausibility. Coherence is essentially dependent upon coreference. Plausibility is dependent upon the interpretation the subject is able to assign to a discourse in an appropriate temporal, spatial, causal and intentional framework" [Ehrlich and Charolles, 1991), p.276].

Therefore, a set of questions emerge at this point: if "they don't exist yet, and when they do, they probably won't look like real trees" (Kunzig, 2010), why are these objects portrayed to resemble real trees? Is it to provide an element that could ring true with our experiences, views, and beliefs (narrative fidelity and aesthetic functionality)? Is it to provide a satisfactory answer to some of the questions and concerns raised by the public about these technologies? (Table 1).

Table 1 Some concerns and questions about air-capture technologies that emerged in a public dialogue on geoengineering conducted by the UK Natural Environment Research Council

Air capture
Disadvantages and concerns:
• The capture devices may be an eyesore and could take up land space
• Visual appearance and potential noise
• There are not many places to store CO_2 underground
Participant's questions to scientists:
• What is the process by which CO_2 is captured?
• How big would they be?
• What would they be made out of?
• Would there be health benefits for those living near them?

Source: Natural Environment Research Council (2010)

As this illustration suggests, the entanglement of imaging and imagining of geoengineering brings to light the technoscientific ideal that orients research towards the acquisition of a demonstrable capability of control. Although transgressing the categories of the natural and the artificial – by shaping and reshaping the features of the world according to visions of how it could be – the familiar and mundane representation of this object of geoengineering research, as well as its implicit 'anticipatory performativity', confers a sense of plausibility that contrasts with the incomplete, uncertain, and inconsistent knowledge that a 'technoscience-in-the-making' can provide.

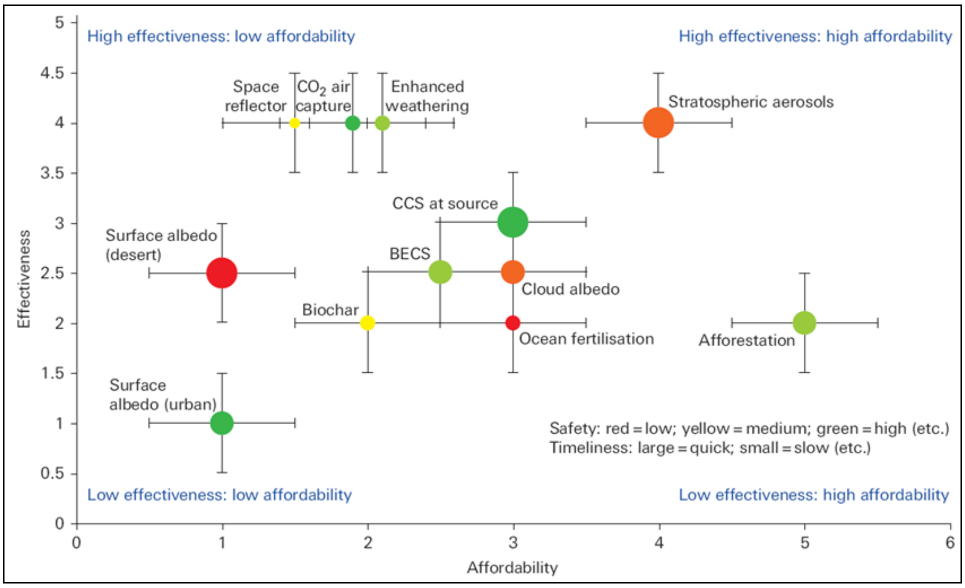
4.2 How plausible are geoengineering facts?

The second image that drew our attention, and pointed to other possible directions for analysing the plausibility of pictorial narratives of geoengineering, was included in the report issued in September 2009 by the UK Royal Society (Royal Society of London, 2009) – Figure 3.

The [con]text where this figure appeared is very explicit about its purpose and the uncertainties that surround different geoengineering methods: this figure was meant to provide a provisional overall evaluation based on different methods discussed in the Royal Society's report, which "should be treated as no more than a preliminary and somewhat illustrative attempt at visualising the results of the sort of multi-criterion evaluation that is needed" [Royal Society of London, (2009), p.49], and "may serve as a prototype for future analyses when more and better information becomes available". As explained in the text "indicative error bars have been added to avoid any suggestion that the size of the symbols reflects their precision – but note that the error bars are not really as large as they should be, just to avoid confusing the diagram" [*idem ibidem*].

From the perspective of reception theory, this textual explanation not only provides the elements necessary to clarify the point of view of the author-imager, thereby guiding the reader viewer in the process of meaning making, but also reveals the author/imager's concerns in terms of narrative probability (coherence) and narrative fidelity (truthfulness and reliability).

Figure 3 A preliminary overall evaluation of the geoengineering techniques considered in Chapters 2 and 3 of the Royal Society's report (see online version for colours)



Source: Royal Society of London (2009, p.49) (reproduced by kind permission of the Royal Society of London)

Despite the efforts to clarify its 'functional adequacy' that is, the limits of its potential uses in acts of communication and "the correct type of intentional relationship to its subject matter" [Mitchell, (1992), p.220], the narrative structure of this image and the contexts in which it has been reproduced and analysed tend to underestimate the uncertainty that surrounded its production and the caveats regarding its uses, thereby stretching its original purpose and meaning and leading to a range of different considerations as to the most promising geoengineering schemes and the resulting rank of preferred geoengineering actions (Table 2).

Table 2 Some quotations retrieved from the internet, with implicit or explicit reference to Figure 3

"(...) But the study does break new ground in attempting to rank the different contending technologies according to how effective they're likely to be, how much they're likely to cost, how safe they appear, and how quickly they could be deployed. So the most cost-effective, overall, is probably pumping dust into the upper atmosphere, mimicking the impact of volcanic eruptions that are known to produce a net cooling by reflecting sunlight back into space." Source: Black, R. (2009) *Plan B for Planet Earth* [online] http://www.bbc.co.uk/blogs/thereporters/richardblack/2009/09/plan_b_for_planet_earth.html (accessed 10 June 2013).
"This diagram provides a solid overview of the schemes the authors examined and their overall assessment of their effectiveness, timeliness, affordability and degree of risk." Source: Jacquot, J. (2009) *Focus on Climate Mitigation; Give Geoengineering a Chance* [online] http://arstechnica.com/science/2009/09/focus-on-climate-mitigation-give-geoengineering-a-chance/ (accessed 10 June 2013).

Table 2 Some quotations retrieved from the internet, with implicit or explicit reference to Figure 3 (continued)

"While the numbers assigned to effectiveness, affordability, safety and timeliness are somewhat qualitative (hence the error bars – which merely denote large uncertainties), this representation gives a sense of which geoengineering approaches might be the more promising ones. In crude terms, the ideal method would be represented by a large green circle to the upper right of the chart. Under these criteria, using stratospheric aerosols to scatter sunlight away from the earth comes closest to the ideal." Source: Maynard, A. (2009) *Geoengineering the Climate: A Clear Perspective from The Royal Society* [online] http://2020science.org/2009/09/01/geoengineering-the-climate-a-clear-perspective-from-the-royal-society/ (accessed 11 June 2013).
"Reflective technologies could cool the planet within a year, and according to the Royal Society's findings the most promising method in terms of cost and effectiveness would be to pump sulphate particles into the stratosphere." Source: Brahic, C. (2009) *Top Science Body Calls for Geoengineering 'Plan B'*, New Scientist, 1 September 2009 [online] http://www.newscientist.com/article/dn17716-top-science-body-calls-for-geoengineering-plan-b.html (accessed 11 June 2013). "The authors rated various schemes on the basis of effectiveness, affordability, safety and timeliness, with estimates of uncertainty for the first two parameters. There were no clear winners: options that scored highly on effectiveness scored low on safety or cost, whereas those that were affordable and safe were less effective." Source: Williamson, P. (2011) 'Climate geoengineering. Could we? Should we?', *IGBP's Global Change*, January, Vol. 76, pp.18–21 [online] http://www.igbp.net/ (accessed 11 March 2013).

As we can see through these quotations, a figure that was conceived as a starting point for future research runs the risk of being seen as the culminating point of research already done. In fact, this image does not conform to the traditional sketches that one would expect to find at the start of an investigation (Gooding, 2004). It points to the complex issues of visualisation and visual communication in science and the interdependencies that exist among the elements and arguments represented in Pauwel's framework (Figure 1).

As the following list may suggest, this single figure and the discourses that surround it seem to offer a wealth of opportunities for reflection about important features of plausible judgement under conditions of severe uncertainty – that is, when probabilities are non-measurable or unknown, and when the space of possible events is only partially identified (Brandolini and Scazzieri, 2011):

- the idea of 'epistemically authoritative sources' as a substantive basis of plausibility (Gabbay and Woods, 2005b; Rescher, 2006)
- the dissemination of knowledge, and the communication of science among professionals and to the public
- the intertextuality associated with this type of representation
- the roles that these kinds of images play in the process of knowledge production
- the paradoxes related to the visual representation of uncertainty
- the *quantitative imperative*[5] versus the *imperative of presuppositions* (Niaz, 2009)

- the need to tackle the dilemmas of the science-policy interface, i.e., the difficulty of accommodating the "growing expectations for science", which has to simultaneously address issues of policy relevance, scientific quality, and legitimacy in a context where "facts are uncertain, values in dispute, stakes high and decisions urgent" (Funtowicz and Ravetz, 1993).

In fact, the types of use and claims attached to Figure 3 not only point to the difference between the meaning making role of an image's pictorial content and its pictorial form or syntax (Barbatsis, 2005), but also bring to the discussion of geoengineering plausibility the concept of 'reliability' – thus, recalling Rescher's idea of *epistemically authoritative sources* (Rescher, 2006), according to which "a thesis is more or less plausible depending on the reliability of the sources that vouch for it" (Rescher, 2003).

The contexts of use of this figure also turn our attention to the ever-growing circulation of information worldwide (mainly on the internet) and how easy it is to distribute, copy, transform, and recombine images, thus facilitating rapid appropriation (or misappropriation), sometimes for uses that were not originally intended. This situation not only undermines the established rules of graphic communication, but also disrupts the familiar practices of image production and exchange (Mitchell, 1992).

The attempt to represent and visualise system uncertainties with the traditional language of science seems to run into a profound paradox: how can we address what is not fully known in a scientific problem with the same (and expected?) quantitative scientific tools and concepts that are used to communicate what is known? Science is by definition related to knowledge and what can be logically and rationally explained. In this attempt to understand system uncertainties, to explain the inexactness of scientific knowledge, and to communicate the limits of what can be known, science has primarily been using numerical language, the language of objectivity, namely what we have been educated to think of as the *language of precision*:

> "A political demand for scientific consensus and unambiguous quantitative information in the assessment process would be likely to grow as science moves nearer to the context of policy making and the political process surrounding the climate negotiations." [van der Sluijs et al., (1998), p.59]

The risk is clear: we may have been led to overestimate what we know about uncertainty and to underestimate the inexactness, unreliability, and – most of all – ignorance of it.

This paradox, linked with the imperative for precision in the field of scientific communication about 'system uncertainties', is clearly seen in an article published in *Science* about the challenges of visualisation and communication of uncertainties resulting both from incomplete or disputed knowledge and from indeterminacy of the future (Spiegelhalter et al., 2011). Although drawing attention to the emphasis that has been given to probability and risk assessment approaches, the authors question not only the uncertainties of those approaches – "What if we're uncertain about probabilities?" – but also the inadequacy of adopting such approaches in a context of "post normal science" (Funtowicz and Ravetz, 1993).

4.3 How plausible is the idea of a robust governance structure for geoengineering?

Many of the questions that have been raised about the plausibility of geoengineering concern the various governance challenges that these proposals encompass (Gardiner, 2011a; Keith et al., 2010b; Bodansky, 2012; Bodle, 2013). In fact, the most intense and stormy controversies in geoengineering are more about the question of political control over the development and deployment of its associated technologies, as well as about underlying moral uncertainties – "a lack of commonly shared normative yardsticks to underpin collective decision-making" (Hansen, 2010) – than about scientific and technical issues.

Although no clear dividing line can be drawn between research and deployment[6] (Bodle, 2013; Parson Edward and Ernst Lia, 2013), legal experts in this field generally agree that governance for geoengineering research should be addressed separately from governance for deployment of geoengineering activities (GAO, 2009).

Discussions about governance mechanisms and basic principles to guide geoengineering research tend to highlight the profound reorientation of technoscientific practices in contemporary societies – in what has been seen as a major shift from the laboratory ideal to the field ideal of experimentation (Schwarz and Krohn, 2011).

> "But what if the object of your interest is not modular or encapsulated? What do you do then? For that, after all, is the feature that big 'G' geoengineering proposals have in common. They call for interventions on systems that lack just this characteristic. You cannot encapsulate part of the atmosphere and it is too complex to be able to build a realistic non-virtual model at scale. As such, it is reasonable to ask whether we could ever have a sound basis for moving to full deployment of any such proposed intervention. And if not, then why bother to even research such proposals in the first place?" (Bunzl, 2009)

However, the question of "whether a technology program is modular and contained or whether it involves the release of material into the wider environment", as well as many others concerning 'risk factors' which have taken priority in the contemporary debate on geoengineering (Bracmort et al., 2011), are far from exhausting the challenges that the governance of research and experimentation encompass.

As Clive Hamilton reminds us, before we embrace the idea that "we should at least do the research", we must address some pressing questions in need of answers: Who is this 'we'? Who should pay for the research? Who should oversee and regulate the research? Who should impose ethical standards? Should the research be transparent, or should it be secret? Who should own the results of the research?... (Hamilton, 2013). Only after we have been given satisfactory answers to these 'hard question' can we start developing the means to engineer the climate.

Moreover, by acknowledging that the scientific enterprise cannot be excused from moral considerations, nor thought of as something entirely outside the realm of action (Strand, 2002), we not only draw attention to the absence of any sharp boundary between facts and values, but also emphasise the close relationship between knowledge and action, thereby suggesting the importance of considering the connection between theoretical and practical discourse in the field of geoengineering. Accordingly, though it seems reasonable to assume that the regulatory needs of geoengineering research are different from those of full-scale deployment, when we consider both the methodological and moral issues that these activities entail we come to recognise that this boundary is permeable and often indistinct.

We thus suggest that before considering the question of whether *it is reasonable to believe* that a set of principles[7] (Rayner et al., 2013) and governance mechanisms (SRMGI, 2013) could in fact ensure that "where research does proceed, it is safe, ethical, and subject to appropriate public oversight and independent evaluation" (Hanafi and

Hamburg, 2013), we should start by addressing the question of if *it is reasonable to do so*.

The image that we selected to illustrate some of the implausible ideas underpinning the idea of a robust governance structure for geoengineering was published in the *Society Matters* blog of the Open University (Corry, 2012) – Figure 4. It recalls a question already asked by Robock (2011): "Whose hand is on the thermostat?".

This image has the power of reminding us that recent proposals to geoengineer the climate are just one contemporary manifestation of man's long-standing desire to control nature – an early-21st-century embodiment of the Baconian project of human mastery over nature.

Figure 4 Whose hand is on the thermostat? (see online version for colours)

Source: Corry (2012); cartoon by Catherine Pain (reproduced by kind permission of the Open University)

The perfect control that the human hand exerts over the thermostat seems intended to extinguish the sense of trepidation that arises from the transformative capacity of modern technologies, from their stated aspiration to manipulate the natural world, and from their power to perform and to surprise us (Bensaude-Vincent et al., 2011; Lee, 2012). However, on trying to address Robock's question that this image evokes, two possible and opposed interpretations come to mind:

- First, that this hand is a legitimate hand; a hand that represents our capacity to overcome the current political inertia on climate change – the weak political leadership, the power of the fossil fuel lobby, the pervasive wishful thinking and the culture of denial that have undermined plan A (Hamilton, 2013) – and that after an obstinate resistance, we were able to establish legitimate geoengineering institutions that invoke the appropriate norms of justice and community (Gardiner, 2010; Gardiner, 2011b).
- Second, that this hand is an illegitimate hand; a hand that not only failed to address the problem of political inertia, but by trying to operate with its constrains, was able to license illegitimate geoengineering activities, violating the kinds of norms of global justice and community that dealing with the problem of climate change might suggest (Idem).

The inconsistencies and implausibility of the first interpretation seem clear:

> "The 'we should at least do the research' lobby assumes that, if geoengineering research succeeds and the situation calls for deployment, it will be done in a way that respects the scientific evidence and protects the interests of the poor and vulnerable. Do we really believe that? The irony is that if we did believe in such a world, there would be no need for research into geoengineering." (Hamilton, 2013)

But how (im)plausible is the second interpretation? In fact, if we look at the past, if we agree that technical artefacts have political qualities, that is, that they can embody specific forms of power and authority and "that the adoption of a given technical system actually requires the creation and maintenance of a particular set of social conditions as the operating environment of that system" (Winner, 1980), we would have to acknowledge that there is a clear risk that the second interpretation of this image is far more plausible than a first glance could suggest.

5 Final remarks

Since the mid-1980s, when the Earth System Sciences Committee of the NASA Advisory Council put forward a more complete and unified approach to Earth studies a new way of understanding and studying the Earth system began to gain ground among scientific institutions around the world – Earth System Science (Earth System Sciences Committee, 1988, 1986). This new approach to Earth studies and global change, the recognition that humanity itself has become a global geophysical force, allied with new approaches and a growing commitment to achieving successful and effective planetary stewardship, are leading to a profound reorientation of the global environmental change research agenda, thereby opening up a wide range of new practices, techniques and mechanisms for global governance.

> "The advent of the Anthropocene, the time interval in which human activities now rival global geophysical processes, suggests that we need to fundamentally alter our relationship with the planet we inhabit. Many approaches could be adopted, ranging from geoengineering solutions that purposefully manipulate parts of the Earth System to becoming active stewards of our own life support system." (Steffen et al., 2011)

It is against this background that the idea of geoengineering, as a potential new tool for addressing climate change, is gaining ground. In fact, each new step in the direction of an integrated Earth System Science seems to have reinforced the plausibility of geoengineering proposals within the wide range of options "towards good planetary management" (Steffen and Tyson, 2001). Accordingly, the first step towards understanding why geoengineering "migrated from marginal to mainstream science and policy making" (Scott, 2012) should consist of a critical examination of the salient narratives that captured the shift in the relationship between humans and the global environment, in order to suggest the beginning of a potentially new geological epoch in which human beings appear to have become a driving force in the evolution of the planet and geoengineering starts to look acceptable in preventing the worst effects of climate change.

As Roland Barthes noted "there are countless forms of narrative in the world (...), each of which branches out into a variety of media, as if all substances could be relied upon to accommodate man's stories" (Barthes, 1975). By contending that reasoning can be discovered in all sorts of symbolic actions (non-discursive as well as discursive), Fisher (1987, 1985) introduced the concept of narrative rationality, suggesting that its application to specific stories[8] may further clarify its nature and value. It was in line with these ideas that we proposed to examine the pictorial narratives of geoengineering. By drawing on Fisher's narrative paradigm – with its associated concept of narrative rationality – we highlighted the importance of looking at the narrative fidelity and narrative probability of the visual representations of geoengineering in order to examine the plausible and implausible aspects of geoengineering stories. Hence, by focusing our attention on the concept of plausibility, we adopted a visual narrative approach to interpret and assess the sense making structures of a set of pictorial narratives of geoengineering and to identify the particular instances of these narratives that provide (or not) a reliable, trustworthy, and desirable guide to thought and action.

As we have shown in the previous sections, the pictorial narratives of geoengineering illustrate the ambiguous epistemic status of plausible reasoning. Indeed, the considerations of reasonability and plausibility that lie at the heart of the geoengineering narratives should be understood as manifestations of a reasoning process in between two theoretical traditions:

1 the instrumental technical rationality of modern conceptions of scientific reasoning

2 the tradition of practical reasoning that draws on practical value rationality to challenge the logical empiricism, its ontological privileging of scientific knowledge, and the adequacy of 'instrumental rationality alone'.

Plausible reasoning tends to be defeasible and inconclusive, "meaning that even when it is in favor of the truth of a proposition, it leaves open the possibility that further evidence could come in that would be in favor of the falsity of that proposition" [Walton, (2003), p.172]. This kind of reasoning is typically used in persuasion dialogue and is highly characteristic of ethical justification argumentation. However, it is also used in scientific argumentation, particularly at "the so-called discovery stage, where a hypothesis is being constructed, even though no (or few) experimental results are in yet" (Idem, p.214) – which is precisely the stage at which geoengineering finds itself. As we hope to have illustrated, although plausible reasoning is required for many matters that science cannot address, there are at least three different areas where the scientific method itself depends heavily on plausible reasoning: "(1) the formulation of hypothesis to be tested, (2) the devising of experiments to test them, and (3) the selection of which unrefuted hypothesis should be provisionally accepted (because although experiments can refute general assertions about the world, they cannot give them positive support without the aid of plausible reasoning)" [Hodgson, (2012), pp.39–40].

In the field of geoengineering, where the promises of scientific and technological developments seem to give place to more and more uncertainty and the feeling that our ignorance is more important than what we know, we highlighted the important role that plausible reasoning play in addressing our two initial questions: *what is it reasonable to believe?* and *what is it reasonable to do?*

As the three images included in this paper suggest, plausibility tends to play a prominent role in the entanglements of imaging and imagining of geoengineering. As we hope to have been able to demonstrate, these are entanglements of the present and the future, of the world in which we live and of worlds that might be realised; of a science that has to deal with our incomplete, inconsistent, and uncertain knowledge and a science that aspires to precision and exactitude; of a humanity constrained by its very nature and a humanity that aspires to transcend its own nature. In fact, plausible reasoning not only plays a central role in the discovery, pursuit, and justification of geoengineering hypotheses, but also constitutes the fundamental practical epistemic device through which we make sense of geoengineering narratives, articulate the entanglements of imag(in)ing geoengineering, and seek the answers to our fundamental questions.

Although highlighting the key role of plausible reasoning in the field of geoengineering, it is important not to forget that prudence is essential in its application. Thus, by drawing on Rescher's Fundamental Rule of Presumption[9], we stress the importance of considering plausibility as the fundamental instrument of epistemic prudence, closely analogous to the prudential principle of action.

Lastly, we would like to emphasise that the narrative paradigm not only predicates that all human discourse (including scientific ones) is meaningful and is subject to the tests of narrative rationality, but also lays the ground for a more sophisticated model of public engagement with science. Thus, in line with Fisher's (1987, 1985) perspective on the role of the public in assessing *public moral arguments*, we support the need to subject the scientific debate on geoengineering to more open and critical reflection. Ultimately, it is hoped that this perspective will stimulate the ability of decision-makers to reason critically about alternative courses of action, and might inspire a vision of human enlightenment that goes far beyond the idea of mastery and control over nature to incorporate a proper balance of epistemic humility and epistemic hope, thus providing a cautious approach to action.

Disclaimer

The views expressed in this paper are those of the author and do not necessarily represent the official views of the European Commission.

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Notes

1 Here we refer to Latour's (2008) concept of 'political epistemology', the idea "that the key to the understanding of politics lies in conceptions of science and, more generally, of knowledge acquisition".

2 "(…) in that: a) certain events in the past are interpreted as hanging together by being narrated into a story with a beginning, middle, and end; and b) a story must be ended before it can be explained" (Sandelowski, 1991).

3 The commercial systems that remove CO_2 from air for use in subsequent industrial processes (Royal Society of London, 2009) and the technologies used to maintain safe levels of CO_2 in submarines and spaceships (Keith et al., 2010a) are the most cited examples aimed at demonstrating the technical feasibility of air capture technologies to counteract climate change.

4 Some examples can be seen at the following links (accessed 10 June 2013):

http://ngm.nationalgeographic.com/big-idea/13/carbon-capture-pg2

http://www.earth.columbia.edu/news/2007/story04-24-07.php

http://carboncapture.us/docs/scrubbing_air_graph_080508.jpg.

5 As stated by Michell (2003), "the quantitative imperative is the view that studying something scientifically means measuring it'".

6 This is mainly because there is a widespread perception that to obtain reliable information about the feasibility and risks of a particular geoengineering technique, at a certain stage of the research programme it would require "real-world field experiments that would have to be gradually scaled up" (Bodle, 2013).

7 Drafted by a UK-based team of scholars, the Oxford principles comprise the following five high-level principles for geoengineering governance:

a geoengineering to be regulated as a public good
b public participation in geoengineering decision-making
c disclosure of geoengineering research and open publication of results
d independent assessment of impacts
e governance before deployment.

For a detailed analysis, see Rayner et al. (2013).

8 Although recognising that technical communities have their own conceptions and criteria for judging the rationality of communication, Fisher considered that "the work even of scientists is inspired by stories, hence their discourse can be interpreted usefully from the narrative perspective" (Fisher, 1984).

9 "Presumption favours the most plausible of rival alternatives – when indeed there is one. This alternative will always stand until set aside (by the entry of another, yet more plausible presumption)" (Rescher, 2006).

Contribution to the edited volume of The End of the Cartesian Dream - Beyond the techno-scientific worldview

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Chapter 8 - Geoengineering Dreams

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Abstract

Geoengineering is a term that refers to a broad set of methods and technologies that aim to deliberately alter the climate system in order to alleviate the impacts of climate change - a term that seems to translate into reality the Cartesian dream of a practical philosophy by means of which we could "render ourselves as masters and possessors of nature". In this chapter we propose to question the "end of the Cartesian Dream" by taking into account the imaginaries of science and technology underlying geoengineering proposals. The main focus of our analysis is the Fifth Assessment Report (AR5) of the United Nations Intergovernmental Panel on Climate Change (IPCC), which includes, for the first time in this report series, an assessment of geoengineering solutions. As the results of our analysis suggest, the Cartesian mechanistic worldview, with its emphasis on the instrumental mastery of nature, is deeply embedded in the dominant techno-scientific framing of climate change and in the range of practices that have produced the 'coupled human and ecological system' as a 'thinkable' and governable domain.

1. Introduction

More than half a century ago, in his book *Landmarks of Tomorrow*, Peter Drucker described his "tangible present" − a period of fundamental shift in worldview − as an age of transition and overlap (Drucker 1957). According to Drucker, this was an age where the Cartesian worldview of the past three hundred years was still providing the means of expression, standards of expectations and tools of ordering, but was no longer acting effectively, and where "the new post-Cartesian, post-modern world", though controlling human action and its impact on the world, was still lacking definition, vocabulary, methods and tools.

While discussing the philosophical shift from the Cartesian universe of mechanical cause to the new universe of pattern, purpose and processes, Drucker identifies the twofold contribution of Descartes to the modern world:

- first, its basic axiom about the nature of the universe and its order − a lawlike, mathematically determinate universe whose intelligibility became clearly expressed in the classic definition of science proposed by the Académie Française[i]: "the certain and evident knowledge of things by their causes";
- second, inspired by the "long chains of utterly simple and easy reasonings that geometers commonly use to arrive at their most difficult demonstrations" Descartes provided the method to make his axiom effective, that is: a "method that contains everything that gives certainty to the rules of arithmetic and that teaches one to follow the true order and to enumerate exactly all the circumstances of what one is seeking" (Descartes 1988, 11-12).

Although recognising that few philosophers since Descartes have accepted his substantive claims or have followed him in his answers to the major problems of systematic philosophy, Drucker still considered that the dominant worldview of the modern West was the Cartesian worldview: "More than Galileo or Calvin, Hobbes, Locke or Rousseau, far more even than Newton, he determined, for three hundred years, what problems would appear important or even relevant, the scope of modern man's vision, his basic assumptions about himself and his universe, and above all, his concept of what is rational and plausible" (Drucker 1957, 2).

But if this is so, it is because Descartes' legacy to the modern world cannot be reduced to its basic axiom about the nature of the universe and its intelligibility, neither to the method upon which one would be able "to establish anything firm and lasting in the sciences". In fact, the epistemological ideals of clarity, detachment and objectivity that Descartes bequeathed to modern science can only be understood if we consider the underlying "Cartesian anxiety" that hovers in the background, and which has spread to all areas of human inquiry and activity (Bernstein 1983). As Hannah Arendt reminds us, the two nightmares that haunt Cartesian philosophy − the possibility that all we take for reality is only a dream, and that man may be nothing more than a plaything at the hands of an all-powerful malicious demon − became the nightmares of the whole modern age (Arendt 1958, 277, 279). The dark side of the Cartesian dream thus forces us to look at Descartes' legacy from a perspective that tends to expose the obsessive concern with the loss of certainty that became decisive for the whole development of modern thought, and which is inseparable from the all-pervasive radical doubt that form the crux of Descartes' method.

Descartes' doubt concerning the reality of everything (*de omnibus dubitandum est),* and his attempt to conceptualise this modern doubt − the search for an Archimedean point that could serve as a foundation upon which we could ground our knowledge − has profoundly influenced our modern worldview, transforming the way we think about the universe, ourselves, nature, God and knowledge, and determined the problems, metaphors and questions that have since then been at the centre of philosophy (Bernstein 1983, Tlumak 2007, Capra 1983). As Hannah Arendt has pointed out, modern philosophy and thought began with the rise of the Cartesian doubt. In its radical and universal significance, the Cartesian doubt became the invisible axis around which all thinking has been centred, occupying much the same vital position as that occupied by the ancient Greek *thaumazein* (Arendt 1958) − the attitude of wondering that inaugurated the ascending development of philosophy, and which, according to Brentano, made it vigorous (Mezei and Smith 1998)[ii].

From this perspective, to question the end of the Cartesian dream is not only an attempt to articulate the reconstruction of an alternative understanding of scientific knowledge without the foundational metaphor that lies at the very basis of Cartesian philosophy, but it is also an attempt to understand how far we have come from the worldview that derived from it and from the problems, metaphors and questions that Descartes bequeathed to the modern age.

It is against this background that we propose to look at current proposals for the deliberate manipulation of the Earth's climate in order to alleviate the impacts of climate change. The assumption that geoengineering proposals can provide a privileged perspective from which to address the aforementioned questions follows from three lines of reasoning:

- First, because geoengineering seems to translate into reality the Cartesian dream of a practical philosophy by means of which we could "render ourselves as masters and possessors of nature", it can help us gain insight into current narratives of science and technology that purport scientific and technological innovation as the solution to our current environmental problems, and give meaning to human action within nature.
- Second, inasmuch as climate engineering can arguably be considered as a typical scientific field that "not only generates knowledge but also increases ignorance concerning the possible side effects of scientific innovation and their technological application" (Böschen et al. 2006, 294)[iii], it constitutes a pertinent locus from which to investigate the far-reaching epistemic consequences of moving from the Holocene to the Anthropocene[iv], i.e. to a "new geologic epoch" where the epistemic ideal of the certainty of scientific knowledge seems to coexist with − or have increasingly been replaced by − a new sort of "science-based ignorance"[v] (Ravetz 1990) that not only threatens our faith in sciences, but also threatens our new man-made world.

- Lastly, the efforts that have been made to address the array of ethical concerns associated with geoengineering (and which are far from being restricted to its unintended side effects[vi]) offer some useful insights into the attempts that have been made to overcome the illusory dichotomies between mind and matter, facts and values, and subject and object, which lay at the very heart of Cartesian philosophy and of the worldview derived from it.

The main focus of our analysis is the Fifth Assessment Report (AR5) of the United Nations Intergovernmental Panel on Climate Change (IPCC)[vii], which includes, for the first time in this report series, an assessment of geoengineering technologies. After a brief description of how geoengineering technologies are assessed in the three Working Group (WG) contributions to the AR5, we will critically examine the scientific and technical ideas underlying geoengineering proposals in order to address the three main questions of this chapter, which are:

- To what extent have we moved away from the Cartesian belief in scientific truth and from the worldview derived from it?
- How have we reconstructed an alternative understanding of scientific knowledge without the foundational metaphor that lies at the very basis of Cartesian philosophy?
- Is geoengineering bringing into reality the Cartesian dream of rendering man the master and possessor of nature?

2. The Science of Geoengineering: Geoengineering in the Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change

In its Fourth Assessment Report (AR4), released in 2007, the IPCC stated that “Geo-engineering options, such as ocean fertilization to remove CO_2 directly from the atmosphere, or blocking sunlight by bringing material into the upper atmosphere, remain largely speculative and unproven, and with the risk of unknown side-effects” (IPCC 2007, 15). However, since the publication of the AR4, geoengineering has attracted increasing attention as a means to address climate change, having been "transformed from a topic discussed largely in science fiction and esoteric scientific papers into mainstream scientific and policy debate" (Macnaghten and Szerszynski 2013, 465). The “grossly unsuccessful” efforts to lower carbon dioxide emissions (Crutzen 2006) — a symptom of what has been described as a “problem of political inertia” (Gardiner 2010, 286-287) — the resonant call for greater planetary management and Earth-system control (Global Environmental Change Programmes 2001), and the tendency to favour transformational rather than incremental responses to climate change (New et al. 2010) are all factors that may help explain why the scepticism and suspicion with which geoengineering was greeted is now giving way to a more pragmatic and serious consideration of its latest scientific and technological breakthroughs and the challenges ahead.

2.1 - The IPCC Expert Meeting on Geoengineering: The definitional issues

Against this background, in June 2011 the IPCC convened a joint Expert Meeting of WGI, WGII, and WGIII to discuss the latest scientific basis of geoengineering, its impacts and response options, and to identify key knowledge gaps for consideration by the author teams of the IPCC's Fifth Assessment Report (IPCC 2010, 2012).

The expert meeting proposed the use of a coherent framework for assessing geoengineering technologies across the three IPCC AR5 Working Groups, having identified the following preliminary set of criteria: effectiveness, feasibility, scalability, sustainability, environmental risks, cost and affordability, detection and attribution, governance challenges, ethical issues, social acceptability, and uncertainty related to all these criteria. It was then expected that the consistent treatment of geoengineering options across the three contributions to the Fifth Assessment Report would add to a better understanding of: (i) the physical science basis of geoengineering (WGI), ii) the impacts of geoengineering proposals on human and natural systems (WGII), and iii) the role of geoengineering within the portfolio of response options to anthropogenic climate change (WGIII).

As stated in the meeting report, a substantial amount of time was spent discussing terminology in and around geoengineering (Boucher, Gruber, and Blackstock 2011). Accordingly, the summary of the synthesis session not only provided the set of common definitions for the terms "Geoengineering" (Box 1), "Solar Radiation Management" (SRM) and "Carbon Dioxide Removal" (CDR) to be used in the Fifth Assessment Report, but also presented an illustration of the conceptual relationship between these terms and those of mitigation and adaptation[viii], as used by the IPCC in its Fourth Assessment Report (Figure 1).

"Geoengineering refers to a broad set of methods and technologies that aim to deliberately alter the climate system in order to alleviate the impacts of climate change. Most, but not all, methods seek to either (1) reduce the amount of absorbed solar energy in the climate system (Solar Radiation Management) or (2) increase net carbon sinks from the atmosphere at a scale sufficiently large to alter climate (Carbon Dioxide Removal). Scale and intent are of central importance. Two key characteristics of geoengineering methods of particular concern are that they use or affect the climate system (e.g., atmosphere, land or ocean) globally or regionally and/or could have substantive unintended effects that cross national boundaries. Geoengineering is different from weather modification and ecological engineering, but the boundary can be fuzzy" (Boucher, Gruber, and Blackstock 2011).

Box 1 - Definition of "Geoengineering" as proposed in the IPCC Expert Meeting on Geoengineering and used in the IPCC Fifth Assessment Report.

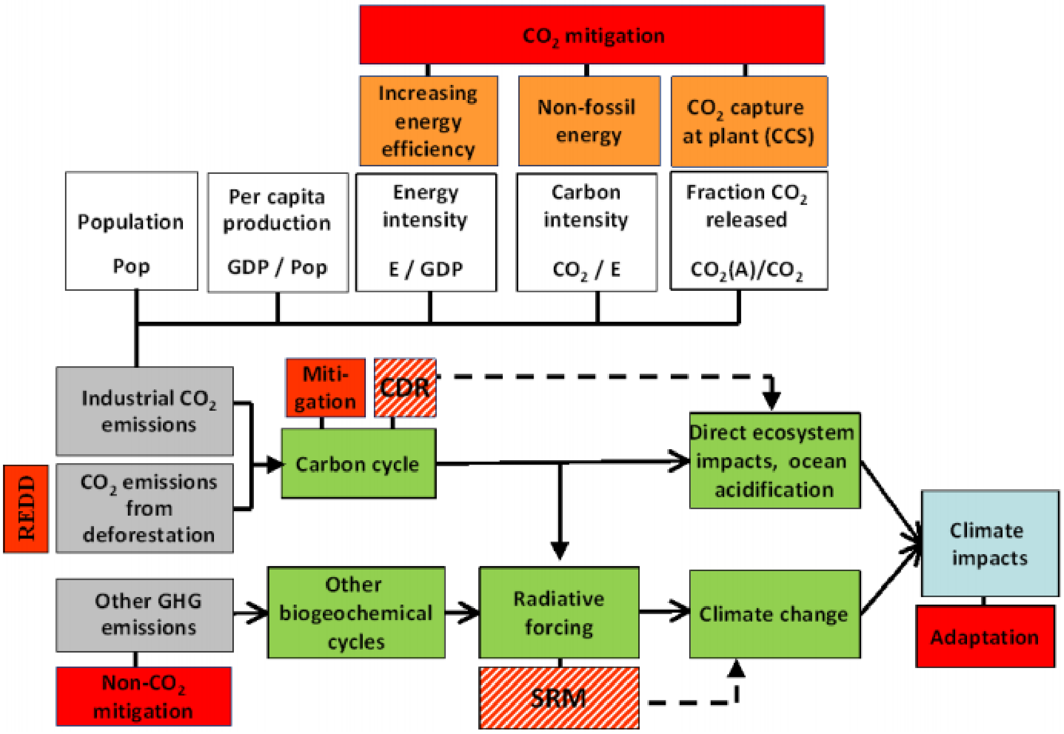

Figure 1: Illustration of mitigation, adaptation, Solar Radiation Management (SRM) and Carbon Dioxide Removal (CDR) methods in relation to the interconnected human, socio-economic and climatic systems and with respect to mitigation and adaptation. The top part of the figure represents the Kaya identity. REDD stands for Reduced Emissions from Deforestation and forest Degradation. (Source: Boucher, Gruber, and Blackstock 2011).

The definition of geoengineering proposed by the Expert Meeting participants seems to take into account previous attempts to identify the key "markers of geoengineering", which are: i) the scale (global or continental); ii) the intent (the deliberate nature of the action rather than a side effect of it) (Schelling 1996), and iii) the degree to which the action is a countervailing measure (Keith 2000). However, special attention should be paid to the inclusion in this list of a new key characteristic of geoengineering methods – that is, that they "could have substantive unintended effects that cross national boundaries".

In fact, as we will see next, the attempt to untangle the ambiguities associated with the term through the identification of this key characteristic of geoengineering actions generates even more obscurity in an already clouded field. This becomes particularly evident when we take into account how uncertainty surrounding geoengineering is addressed across the IPCC AR5 and how the confidence scale[ix] is used to synthesise author team's judgements about the validity of findings in the field. In fact, on the rare occasions where a high or very high level of confidence is assigned to a finding concerning geoengineering, either it refers to the uncertainties about the potential of these technologies to counteract climate change or it refers to the their almost certain side effects that are "difficult if not impossible to forecast" (IPCC 2014c). The following five quotations are illustrative of this (Box 2):

"There is robust agreement among models and *high confidence* that the compensation between GHG warming and SRM cooling is imprecise" (IPCC 2013b, 635).

"There is only limited evidence on the potential of geoengineering by CDR or solar radiation management (SRM) to counteract climate change, and all techniques carry risks and uncertainties (*high confidence*)" (IPCC 2014d, 7).

"The level of *confidence* on the effects of both CDR and SRM methods on carbon and other biogeochemical cycles is *very low"* (IPCC 2013b, 552).

"The knowledge base on the implementation of SRM and CDR techniques and associated risks is presently insufficient. Comparative assessments suggest that the main ocean-related geoengineering approaches are very costly and have large environmental footprints (*high confidence*, Boyd, 2008; Vaughan and Lenton, 2011; Russell et al., 2012)" (Pörtner et al. 2014, 43).

"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 (*high confidence*)" (IPCC 2014e, 13).

Box 2: What is known and unknown about the potential of geoengineering technologies to counteract climate change and about their unintended side effects.

Thus, there seems to be a clear inconsistency between the definition of geoengineering presented in the IPCC AR5 and the main findings presented by the three WG. Would it make sense to review the definition of geoengineering accordingly? What level of scientific credibility could be attached to geoengineering were it to be defined as *a set o technologies and methods that intent to manipulate the climate system to counteract climate change, but whose potential to achieve this goal is still imprecise and whose unintended side effects of large-scale are difficult if not impossible to forecast?*

Moreover, the option to use in this same definition two words with the very opposite meaning ("deliberately" and "unintended") translates much of what has been said about the ignorance generated by science and reflects the growing awareness of the new unresolved problems that arise in the context of scientific and technological applications. But bringing these issues into the very definition of geoengineering is nevertheless surprising, particularly if we consider the scale to which those intended and unintended effects refer to. What account of science and technology can be grasped from a field that defines itself as the intentional intervention in the global climate system to counteract the unintended effects of greenhouse emissions, and which may carry unintended (and unknown) large-scale side effects? And given this definition, what can be said about the research objects of geoengineering? As M. Carrier and A. Nordmann have pointed out "on the technoscientific account, it is no longer possible even to construe objects like the hole in the ozone-layer or the cancer-mouse as natural. They have been created by humans but they constitute objects of scientific research all the same" (Carrier and Nordmann 2011, 4).

2.2 Geoengineering across the three Working Groups contributions to the IPCC Fifth Assessment Report

As suggested by the participants of the IPCC Expert Meeting on Geoengineering, the assessment of geoengineering technologies across the three WG contributions to the IPCC AR5 is presented "within the context of the risks and impacts of climate change and other responses to climate change, rather than in isolation" (IPCC 2012, 4). Accordingly, the physical science basis of CDR and SRM is assessed in Chapters 6 (Carbon and other Biogeochemical cycles) and 7 (Clouds and Aerosols) of AR5 WGI report, while additional impacts of geoengineering proposals on human and natural systems are assessed in Chapters 6 (Ocean Systems) and 19 (Emergent risks and key vulnerabilities) of WGII contribution to AR5. The social, economic and ethical implications of geoengineering are assessed in section 3.7.7 of AR5 WGIII report. Further, section 6.9 of AR5 WGIII report discusses how the use of geoengineering methods can change the relationships between GHG emissions and radiative forcing and their potential role in the context of transformation pathways. Lastly, Chapter 13 (International Cooperation: Agreements and Instruments) assesses the special case of geoengineering governance.

One of the aspects that drew special attention to the WGI contribution to the Fifth Assessment Report of the IPCC was the inclusion of the topic of geoengineering in the final paragraph of the "Summary for Policymakers" (SPM) — perhaps one of the most-read sections of this report series (Box 3).

> "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 CO_2 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 2013c, 29).

Box 3- Reference to geoengineering in the last paragraph of the Summary for Policymakers (SPM) of the Working Group I contribution to the IPCC Fifth Assessment Report (WGI AR5).

Although this paragraph seems intended to convey the alleged policy neutrality[x] of the IPCC, its very presence at the end of the Summary for Policymakers raised several concerns as to the new scientific status that geoengineering appears to have acquired, the way it was prematurely placed on the climate change agenda as a legitimate topic of debate and, thereby, the political leverage that can be exercised over geoengineering research and deployment (ETC Group 2014, Stilgoe 2014) - Box 4.

"In the scientific world, a final paragraph is often the place to put caveats and suggestions for further research. In the political world, a final paragraph is a coda, a big finish, the place for a triumphant, standing-ovation-inducing summary. The IPCC tries to straddle both worlds. The addition of the word "geoengineering" to the most important report on climate change for six years counts as a big surprise (...) There is an argument that the taboo has already been broken and that, like sex education, it therefore has to be discussed. Those of us interested in geoengineering were expecting it to appear in one or two of the main reports when they are published in the coming months. To bring it up front is to give it premature legitimacy"(Stilgoe 2014).

Box 4 - Excerpt of the post "Why has geoengineering been legitimised by the IPCC?" published on the Political Science blog hosted by *The Guardian*.

But the most interesting aspect of this paragraph is that it reflects much of the approach followed by the AR5 author teams to present the key findings of the assessment of geoengineering techniques and their judgments about the validity of those findings. In fact, the almost absence of quantified measures of uncertainty to communicate the degree of certainty in the assessment of CDR and SRM methods, and the option to assign a confidence level to speculative conditional sentences are two aspects of the geoengineering assessment in the AR5 that deserve closer attention. The emphasis on the side effects of CDR and SRM methods is also a key feature of all three WG contributions to the IPCC AR5 that deserves equal consideration. In the remaining part of this section we will focus our attention on these three aspects in order to address the key questions presented in the beginning of this chapter.

When assessing geoengineering technologies, the option to use the quantitative likelihood scale to describe a probabilistic estimate of the occurrence of a specific outcome is confined to CDR methods, particularly when referring to their side effects on carbon and other biogeochemical cycles, or to biogeochemical and technological limitations to their potential. An example of this can be seen in Chapter 6 of AR5 WGI report - Box 5.

"The ‘rebound effect’ in the natural carbon cycle *is likely* to diminish the effectiveness of all the CDR methods".

"Uncertainties make it difficult to quantify how much CO_2 emissions could be offset by CDR on a human time scale, although it is *likely* that CDR would have to be deployed at large-scale for at least one century to be able to significantly reduce atmospheric CO_2. In addition, it is *virtually certain* that the removal of CO_2 by CDR will be partially offset by outgassing of CO_2 from the ocean and land ecosystems".

Box 5- The likelihood of specific outcomes associated with CDR methods.[xi]

Despite the i) low level of confidence on the effectiveness of these methods, ii) the limited evidence on the potential for large-scale deployment of these technologies and iii) their unpredictable (but almost certain) side effects and long-term consequences on a global scale the Representative Concentration Pathway (RCP) scenarios[xii], used as a basis for future projections in the AR5, already include some CDR methods. In fact, long-term mitigation scenarios typically rely on the availability and widespread use of bioenergy with carbon capture and storage (BECCS) and large-scale afforestation in the second half of the century. The political implications of this are clear, as recognised by IPCC WGII: "the increasing dependence of pathways on CDR options reduces the ability of policymakers to hedge risks freely across the mitigation technology portfolio". But what does this tell us about the assumptions underlying RCPs with lower radiative forcing levels? What imaginaries of science and technology inform these RCPs? What visions of nature are embedded in these scenarios? What images of the relationship between man and nature are portrayed in the overshoot scenarios?

But perhaps one of the most intriguing aspects of the assessment of geoengineering conducted by WGI refers to the level of confidence assigned to conditional sentences in order to communicate the degree of certainty in key findings (Box 6).

> "Theory, model studies and observations suggest that some Solar Radiation Management (SRM) methods, if practicable, could substantially offset a global temperature rise and partially offset some other impacts of global warming, but the compensation for the climate change caused by GHGs would be imprecise (*high confidence*)" (IPCC 2013b, 574).
>
> "If SRM were terminated for any reason, a rapid increase in surface temperatures (within a decade or two) to values consistent with the high GHG forcing would result (*high confidence*)" (IPCC 2013b, 635).

Box 6 - Statements of WGI to the AR5.

What can we infer from these statements? Can they be considered policy-relevant? If so, what scientific basis do they provide for policymakers?

If we now return to our initial questions we have to conclude that, although we have long since recognised the severe limitations of the mechanistic paradigm informed by the Cartesian belief in scientific truth, our worldview in still entrenched in it. And this is so because the "alternative" understanding of scientific knowledge − the systemic paradigm that recognises that all scientific concepts and theories are limited and approximate, that science can never provide any complete and definitive understanding and that we always deal with limited and approximate knowledge (Capra and Luisi 2014) − has yet to recognise that there is no point in post-normal science problems in trying to emulate the mechanistic and reductionist views of classical physics in its control of uncertainty (Funtowicz and Ravetz 1990). This is one of the paradoxes of our time. Indeed, the attempt to communicate uncertainties with the traditional language of science seems to run into a profound contradiction: how can we address what is not fully known in a scientific problem with the same (and expected?) quantitative scientific tools and concepts that are used to communicate what is known? Science is by definition related to knowledge and what can be logically and rationally explained. In this attempt to understand system uncertainties, to explain the inexactness of scientific knowledge and to communicate the limits of what can be known science has primarily been using numerical language, the language of objectivity, namely what we have been educated to think of as the language of precision. The risk is clear: we may have been led to overestimate what we know about uncertainty and to underestimate the inexactness, unreliability and – most of all – our ignorance of it.

Moreover, the pressure of practice under which science operates today is giving rise to the emergence of new objects of research through which we gain a new understanding and control of nature (Carrier and Nordmann 2011, Carrier 2011). As the assessment of geoengineering technologies in the IPCC AR5 demonstrates, the techno-scientific framing of climate change, although involving different ways of perceiving man's attempts to 'act into nature', is giving meaning to human action within nature and is providing guidance for humans' domination of nature.

3. The Geoengineering worldview: halfway between the Cartesian dream and the Cartesian nightmare?

In the mid-1980s, when the Earth System Sciences Committee of the NASA Advisory Council put forward a more complete and unified approach to Earth studies – Earth System Science – a new way of understanding and analysing the Earth system began to gain ground among scientific institutions around the world. Fundamental to this approach is a view of the Earth system as a related set of interacting processes operating on a wide range of spatial and temporal scales, rather than as a collection of individual components. Several factors have combined to stimulate this new approach to Earth studies and global change: the maturity of the traditional Earth science disciplines, developments in remote sensing systems and related earth observation activities, advances in conceptual and numerical models of Earth system processes, and the recognition of the growing role of human activity in global change (ESSC 1988, 1986).

A few years after NASA acknowledged the need to strengthen international cooperation for a truly worldwide study of the Earth, the Rio Declaration on Environment and Development and Agenda 21 (a comprehensive plan of action to facilitate the transition towards the goal of truly sustainable development), unanimously adopted by 178 Governments at the United Nations Conference on Environment and Development (UNCED), gave a major boost to the development of an integrated approach to sustainable development and for the interdisciplinary focus of Earth system science and global change (Johnson, Ruzek, and Kalb 1997).

The next important step towards a holistic perception of the Earth system as a whole was taken in 2001 with the establishment of the Earth System Science Partnership (ESSP), which has brought together the four international global change research programmes: DIVERSITAS, the International Geosphere-Biosphere Programme (IGBP), the International Human Dimensions Programme (IHDP), and the World Climate Research Programme (WCRP)[xiii].

The orchestrated effort to integrate disciplinary knowledge, insights and understanding of parts of the Earth system within Earth system science gave rise to the idea of a ‘global system of global systems science’. Seen as a ‘substantive science of integration’, this new system of global environmental science is today presented as the key to implementing any approach towards global sustainability (Steffen et al. 2004).

> ‘The challenge of understanding a changing Earth demands not only systems science but also a **new system of science** …
>
> Human-driven changes are pushing the Earth System beyond its natural operating domain into planetary *terra incognita.* Management strategies for global sustainability are urgently required. **Earth System science is the key to implementing any approach towards good planetary management**, as it can provide critical insights into the feasibility, risks, trade-offs and timeliness of any proposed strategy’ (The Global Environmental Change Programmes 2011, 23-27, emphasis added).

This new way of understanding and studying the Earth system, the recognition that humanity itself has become a global geophysical force, allied with new approaches and a growing commitment to achieving successful and effective planetary stewardship, are leading to a profound reorientation of the global environmental change research agenda, thereby opening up a wide range of new practices, techniques and mechanisms for global governance (Lövbrand, Stripple, and Wiman 2009).

> ‘The advent of the Anthropocene, the time interval in which human activities now rival global geophysical processes, suggests that we need to fundamentally alter our relationship with the planet we inhabit. Many approaches could be adopted, ranging from geoengineering solutions that purposefully manipulate parts of the Earth System to becoming active stewards of our own life support system’ (Steffen et al. 2011, 739).

It is against this background that the idea of geoengineering, as a potential new tool for addressing climate change, is gaining ground. In fact, each new step in the direction of an integrated Earth System Science seems to have reinforced the plausibility of geoengineering proposals within the wide range of options “towards good planetary management” (Steffen and Tyson 2001). Accordingly, the first step toward understanding why geoengineering “migrated from marginal to mainstream science and policy making” (Scott 2012) should consist of a critical examination of the salient narratives that captured the shift in the relationship between humans and the global environment, in order to suggest the beginning of a potentially new geological epoch in which human beings appear to have become a driving force in the evolution of the planet and geoengineering starts to look acceptable in preventing the worst effects of climate change.

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[i] In this respect, it is worth mentioning that this definition of science is still included in the 1762 fourth edition of the *Dictionnaire de l'Académie Française* and only in the sixth edition of 1832 does science become defined by its subject matter, rather than by its method (Lee 2010).

[ii] With this in mind it is worth recalling what Descartes wrote about the first of the six major passions of the human soul (Descartes 1989, articles 70 and 76): "*Wonder is a sudden surprise of the soul which makes it tend to consider attentively those objects which seem to it rare and extraordinary (...) But it happens much more often that one wonders too much and is astonished, in perceiving things worth considering only a little or not at all, than that one wonders too little. This can entirely eradicate or pervert the use of reason. That is why, although it is good to be born with some inclination to this passion, since it disposes us to the acquisition of the sciences, we should still try afterwards to emancipate ourselves from it as much as possible (...).*"

[iii] For an illuminating discussion ofn this topic see for instance (Winter 2012, Hulme 2014, Rayner 2014).

[iv] Paul Crutzen and Eugene Stoermer coined the term Anthropocene to describe a new geological epoch "in which humankind has emerged as a globally significant — and potentially intelligent — force capable of reshaping the face of the planet" (Clark, Schellnhuber, and Crutzen 2004)

[v] J. Ravetz has coined the term "science-based ignorance" to designate "*an absence of necessary knowledge concerning systems and cycles that exist out there in the natural world, but which exist only because of human activities*" (Ravetz 1990, 287).

[vi] Some significant contributions to the discussion of the ethical issues posed by geoengineering include: (Hamilton 2011, 2013, Gardiner 2011, Betz and Cacean 2012, Hourdequin 2012, Preston 2012, Jamieson 2009, 1996, Schneider 1996).

[vii] As defined in the *Principles Governing IPCC Work* "*the role of the IPCC is to assess on a comprehensive, objective, open and transparent basis the scientific, technical and socio-economic information relevant to understanding the scientific basis of risk of human-induced climate change, its potential impacts and options for adaptation and mitigation*" (IPCC 2008, 1). To this end the IPCC produces periodic assessment reports that use a calibrated language to characterise the scientific understanding and associated uncertainties underlying assessment findings. For more information about the treatment of uncertainties in the IPCC Assessment Reports see: (Mastrandrea et al. 2010, Mastrandrea et al. 2011).

[viii] In this regard it is worth mentioning that in the IPCC AR5 the definition of "adaptation" differs in breadth and focus from that used in earlier IPCC reports (IPCC 2014b, a, 2013a). In spite of the fact that the Expert Meeting "did not address the question of whether these definitions should be updated to differentiate them better from geoengineering" (Boucher, Gruber, and Blackstock 2011, p.2), the new term of "adaptation", as defined in the WGII AR5 Glossary, is supposed "to reflect scientific progress". However, the question of whether it resulted from an attempt to better differentiate conventional adaptation approaches from geoengineering proposals is not clear.

[ix] The AR5 relies on two metrics for communicating the degree of certainty in key findings (Mastrandrea et al. 2010):
i) Confidence in the validity of a finding, based on the type, amount, quality and consistency of evidence (e.g., mechanistic understanding, theory, data, models, expert judgment) and the degree of agreement. Confidence is expressed qualitatively.
ii) Quantified measures of uncertainty in a finding expressed probabilistically (based on statistical analysis of observations or model results, or expert judgment).

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[x] The term "policy neutrality" is used here to refer to the *Principles Governing IPCC Work*, which states that "IPCC reports should be neutral with respect to policy" (IPCC 2008, 1).

[xi] In the AR5, the following terms have been used to indicate the assessed likelihood of an outcome or a result: virtually certain 99–100% probability, very likely 90–100%, likely 66–100%, about as likely as not 33–66%, unlikely 0–33%, very unlikely 0–10%, exceptionally unlikely 0–1%.

[xii] Four Representative Concentration Pathway (RCP) scenarios produced from Integrated Assessment Models (IAMs) were used in the Fifth Assessment Report of IPCC as a basis for the climate predictions and projections presented by WGI (AR5 WGI report, chapters 11 to 14). These four RCPs are identified by their approximate total radiative forcing in year 2100 relative to 1750: 2.6 W m^{-2} for **RCP2.6**, 4.5 W m^{-2} for **RCP4.5**, 6.0 W m^{-2} for **RCP6.0**, and 8.5 W m^{-2} for **RCP8.5**. The RCPs with lower radiative forcing levels already include some CDR methods: the RCP2.6 scenario achieves the negative emission rate through the use of large-scale bioenergy with carbon capture and storage (BECCS) and the RCP4.5 also assumes some use of BECCS to stabilise CO_2 concentration by 2100 and, to a lesser extent, afforestation.

[xiii] The ESSP was launched in 2001 as a response to the Amsterdam Declaration on Global Change, which called for closer cooperation between global environmental research programmes and for greater integration across disciplines, environment and development issues, and the natural and social sciences.