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INTERNATIONAL ENVIRONMENTAL AGREEMENTS UNDER THE OPTION OF GEOENGINEERING

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Master Thesis submitted to the Department of Economics of the University of Macedonia in partial fulfillment of the requirements for the degree of Master in Economics.

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I dedicate my work
to my family and
specifically to my
mother for her
support.

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Διεθνείς περιβαλλοντικές συνθήκες κάτω από το πρίσμα της γεωμηχανικής

Περίληψη

Η υπερθέρμανση του πλανήτη ήταν και εξακολουθεί να είναι ένα ακανθώδες ζήτημα για ολόκληρο τον κόσμο. Η απουσία μιας παγκόσμιας εγκεκριμένης λύσης έχει οδηγήσει στην έρευνα νέων μεθόδων για τον περιορισμό αυτού του προβλήματος. Μία από τις λύσεις που προτείνονται σήμερα είναι η γεωμηχανική. Αν και θεωρείται από πολλούς ως μία πολλά υποσχόμενη μέθοδος, υπάρχουν άτομα που εξακολουθούν να διαφωνούν ή τουλάχιστον παραμένουν επιφυλακτικοί για την εφαρμογή της. Τεράστια έρευνα έχει γίνει πάνω στην γεωμηχανική και κατά πόσο είναι κατάλληλη η εφαρμογή της. Ωστόσο, οι εξωτερικότητες της γεωμηχανικής δεν είναι το μόνο θέμα που έχει επιστήσει την προσοχή των επιστημόνων. Η αδυναμία των χωρών στην επίτευξη συναίνεσης για την εφαρμογή της γεωμηχανικής και η ανικανότητα να σχηματίσουν μια διεθνή περιβαλλοντική συνθήκη παραμένει. Η εργασία αυτή ανασκοπεί τον τομέα της επιστήμης που λέγεται γεωμηχανική και την επιστημονική έρευνα που είναι υπέρ και κατά της εφαρμογής της. Επιπλέον, ανασκοπεί την έρευνα που έχει γίνει μέχρι τώρα πάνω στις διεθνείς περιβαλλοντικές συνθήκες σε σχέση με την γεωμηχανική και παρουσιάζουμε τα επιστημονικά αποτελέσματα για το αν υπάρχει η δυνατότητα να σχηματιστεί μια τέτοιου είδους συνθήκη.

Σημαντικοί όροι: γεωμηχανική, διεθνείς περιβαλλοντικές συνθήκες, κλιματική πολιτική, διαχείριση ηλιακής ακτινοβολίας.

International Environmental Agreements under the option of Geoengineering

Abstract

Global warming was and still is a thorny issue for the entire world. The absence of a worldwide approved solution has led in research of new ways to confine this problem. One of the solutions that are nowadays proposed is geoengineering. Although it is believed by many as a promising method there are those who still disagree or at least remain cautious for its implementation. Vast research has been done upon geoengineering and whether it is suitable to deploy it. However the externalities of geoengineering are not the only matter that has drawn scientists' attention. The incapability of countries to reach a consensus upon geoengineering's deployment and the inability to form an international environmental agreement still remains. This paper reviews the field of science that is called geoengineering and the scientific research that is in favor and against its implementation. Also it reviews the research that has been done, till now, upon international environmental agreements in relation to geoengineering and we demonstrate the scientific results of whether there is a possibility to form such an agreement.

Keywords: geoengineering, international environmental agreements, climate policy, solar radiation management.

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SECTION 1

A brief overview of geoengineering

1. Introduction

The human inability to reduce emissions has led to the need for a drastic solution in the increasing problem of global warming. As we know from scientific research, earth's climate is determined by the amount of solar radiation that hits her and the amount of the radiation that stays and does not pass the atmosphere. Human activities and mostly carbon usage has increased the earth's temperature. This happens due to the earth's inability to send back in space the extra carbon that is created. These gases absorb sunlight, thus causing temperature increases. As a result we have the appearance of the greenhouse effect which leads to global warming. A significant drawback that creates further problems is the time lag of global warming which is caused due to the large heat capacity of the oceans. The stabilization of CO_2 concentration would require a 60–80% worldwide reduction in current anthropogenic CO_2 emissions. Nevertheless, fossil fuels provide over 80% of the world's energy, and emissions of CO_2 are actually increasing by around 2% each year (Crutzen (2006)). Although reducing emissions is considered to be the best climate policy against global warming, due to its inability of implementation it is believed that geoengineering will fill the gap by reducing the catastrophic impacts of this phenomenon.

But what really is geoengineering? According to bibliography there is a vast variety of definitions that try to specify and catch the real essence of this field. Geoengineering is defined by the National Academy of Sciences (1992) as the "options that would involve large-scale engineering of our environment in order to combat or counteract the effects of changes in atmospheric chemistry" (Sterck (2011)).

However before we begin analyzing the field of geoengineering is mandatory to say a few words about the history of this science and its origin. The whole idea of geoengineering was generated from some physical phenomena, the eruption of Tambora in Indonesia in 1815, the 1883 eruption of Krakatau, in Indonesia and after that the eruption of mountain Pinatubo in 1991. The eruption of Tambora in Indonesia in 1815 was the prime contributor to the following "year without summer," in which the temperature for the period July–August on the

Iberian Peninsula was 2–3 degrees lower than average for those months (Trigo *et. al.*, (2009)). Larger eruptions, such as the 1883 eruption of Krakatau, in Indonesia, have caused even greater cooling that lasted longer (Victor *et. al.*, (2009)). Last but not least, Mount Pinatubo that was erupted in 1991 lead to a global cooling of about 0.5 °C the following year (Hansen *et. al.*, (1992)). Therefore volcanic eruptions have provided natural experiments by emitting large quantities of sulfur into the stratosphere. After long research scientists understood that sulfate particles have the ability to deflect solar radiation. But their results upon the sulfate particles that were injected into the atmosphere, from these volcanic eruptions, showed that the duration of these particles was very small. So they came with the idea that if they wanted long-run results they needed to inject sulfate particles into the troposphere. Crutzen (2006) supports that "the great advantage of placing reflective particles in the stratosphere is their long residence time of about 1–2 years, compared to a week in the troposphere. Thus, much less sulfur, only a few percent, would be required in the stratosphere to achieve similar cooling as the tropospheric sulfate aerosol (e.g., Dickinson, (1996); Schneider, (1996); NAS, (1992); Stern, (2005))".

But besides all that, geoengineering is not a new idea. In Victor's *et. al.* (2009) paper we find a small historical flashback about the early start of the idea of geoengineering. According to their historical research (Victor's *et. al.* (2009)) "In 1965, when President Lyndon Johnson received the first-ever U.S. presidential briefing on the dangers of climate change, the only remedy prescribed to counter the effects of global warming was geoengineering. That advice reflected the scientific culture of the time, which imagined that engineering could fix almost any problem. By the late 1940s, both the United States and the Soviet Union had begun exploring strategies for modifying the weather to gain battlefield advantage. By the 1970s, after a string of failures, the idea of weather modification for war and farming had largely faded away". However, from recent research, increasing the earth's albedo offers the most promising method for rapidly cooling the planet. Until now, launching reflective materials, like sulfate, into the upper stratosphere seems to be the easiest and most cost-effective option. Scientists began to contemplate that the injection could be accomplished by using high-flying aircraft, naval guns, or giant balloons (Victor's *et. al.* (2009)). Consequently with all this interest upon climate change and the contribution of Stern Review (Stern (2006)), climate change began to be thought as an economic issue.

According to scientific research geoengineering is divided in two methods depending on whether they aim at reducing the greenhouse effect, or at diminishing the share of sunlight that reaches and warms the Earth system. First is the method of Carbon Dioxide Removal or CDR and second is the method of Solar Radiation Management or SRM. CDR seeks to remove CO_2 from the atmosphere in order to reduce the amount of long-wave radiation trapped in the earth's system through the greenhouse effect and includes:

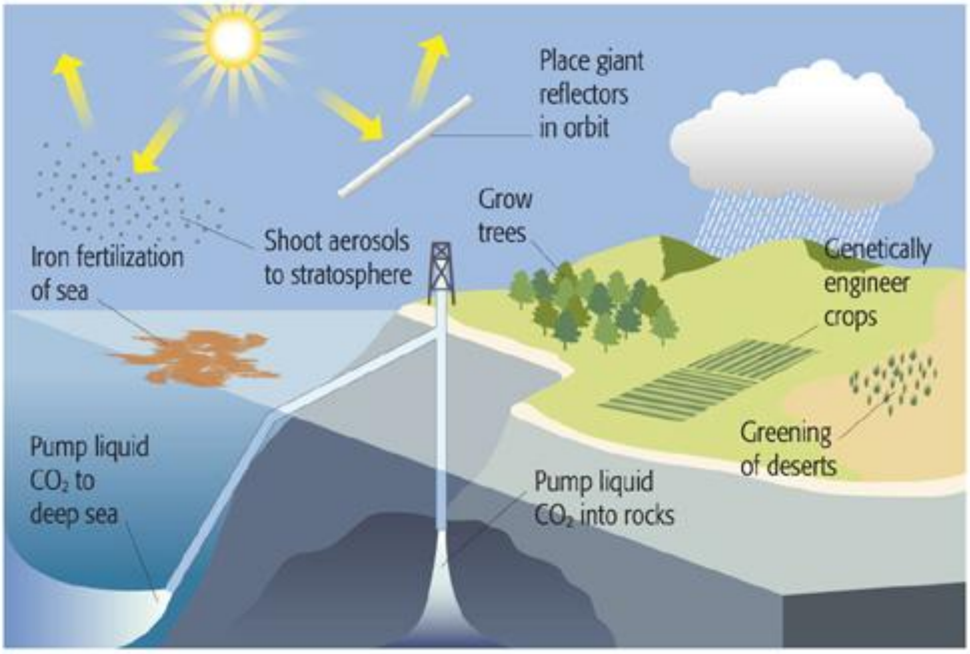
- The extension of the earth's surface covered by trees,
- The increase of the oceanic uptake of CO_2 through enhanced algae and plankton growth, and
- The artificial acceleration of the mineral sequestration of CO_2 or the creation of "artificial trees" that capture CO_2 thanks to a chemical sorbent.

SRM on the other hand aims at repelling short-wave sunlight before the radiation hits the earth's surface and turns into heat, includes methods that block incoming solar radiation or equivalently increase the planet's albedo, which is the capacity of the planet to reflect incoming solar radiation. In short it includes:

- Terrestrial albedo modification,
- Cloud reflectivity enhancement and
- Injection of stratospheric sulfur aerosols.

In the following picture someone can see the proposed methods for the implementation of geoengineering.

GEOENGINEERING SOLUTIONS TO CLIMATE CHANGE



However the real purpose of this paper is not only to analyze the methods used in geoengineering but also to refer to the efforts that are being carried out in order to accomplish international cooperation among countries. This specific achievement is one of the hardest since the past has shown us that the implementation of an international environmental agreement with full participation is a very difficult project due to free riding and other matters as we will see. Consequently we will make a review of the literature that has been published upon geoengineering and upon the implementation of international environmental agreements in this specific field.

In order to result in a global uniform way of reducing emissions, nations assemble many conventions. The goals of the climate change conventions are to stabilize the amount of greenhouse gases in the atmosphere to avoid dangerous man-made climate change. More than twenty years after the founding of the climate change convention, the overall concentration of greenhouse gases has increased. The concentration of atmospheric carbon dioxide increased by 5 % in the period 1995-2005 which is the highest measured decadal increase since recordings began in the 1950s (Intergovernmental Panel on Climate Change [IPCC], (2007)). Most recently the Copenhagen Summit led to the Copenhagen Accord, which aims to limit the increase in global mean temperature, "recognizing the scientific view that the increase . . . should be below 2 degrees Celsius" (Nordhaus (2011)). Yet history showed that the implementation of such agreements is not feasible and appear to be highly problematic. This situation led to research upon the characteristics that an agreement should have in order to be fully implementable and for all nations to consent.

In what it follows we shall focus upon SRM since it is mostly used in bibliographical research. The reason for which this occurs is that the two options of geoengineering, CDR and SRM, differ essentially. While CDR strategies tend to be costly and slow in terms of temperature response (Tavoni (2013)), Solar Radiation Management has been argued to be a more cost-effective solution since it can reduce the effects of global warming relatively quickly (Matthews and Caldeira (2007), Shepherd *et. al.* (2009)) and hence provides a potential game-changing option for climate policy (Swart and Marinova (2010), Victor *et. al.* (2009)). So the term geoengineering will refer to SRM from now on.

This paper is organized as follows. We first analyze the advantages and disadvantages of geoengineering. In Section 3 we will refer to authors that endorse the implementation of geoengineering and to those that oppose. Finally in Section 4 we will show the research that has been done upon the creation of successful International Environmental Agreements. Section 5 demonstrates the conclusions.

SECTION 2

Beneficial and harmful results

2. The two sides of geoengineering

The intention of this section is to analyze the pros and cons of geoengineering. As research has shown every field of science has two sides, one that helps the evolution of humankind and one that has negative consequences. This occurs in geoengineering too.

Particularly there are many advantages, like cooling the climate, reducing ice melting and sea level rise, increasing plant productivity etc. (Emmerling and Tavoni (2012)). According to research the SRM method is thought to be the perfect solution to greenhouse problems. One reason is that while countries implementing geoengineering may be clearly identified, it is much harder to assess which country has to mitigate its emissions, and by how much. But to some the solution that geoengineering provides is far from the reality. Moreover it is observed that the problems that can be aroused after the implementation of geoengineering have drawn the attention of many, so it is inevitable not to mention them analytically and to all of their extent.

There are scientists who strongly disagree with the implementation of geoengineering or at least remain cautious. According to them sometimes what is most believed as a solution it may actually be the beginning of serious problems. Some of the harmful implications for the environment are ocean acidification, extensive droughts, ozone depletion, no more blue skies etc. (Emmerling and Tavoni (2012)). However the most serious drawback of geoengineering is that we do not really know the precise consequences of solar radiation management on the earth's climate and once these methods are applied there is probably no way back (Robock (2008)) i.e. the need for geoengineering to be continued forever. Also it is clear from the bibliography that these consequences will occur if a sudden cessation of geoengineering happens. This kind of threat as Ricke1 *et. al.* (2013) say is depended from both consequences and the possibility of occurrence.

Gramstad and Tjøtta (2010) show the high uncertainty of a geoengineering scheme. Although there has been tremendous effort to research more about geoengineering and its effects on the environment, the uncertainty of its implementation results and the risk of its inertia still remain. Scientists fear the possibility that their research might be useless upon the uncertainty of SRM and as a result they waver (Moreno-Cruz and Keith (2012)). Although it is possible to predict some environmental consequences, it will still be impossible to foresee all the consequences of geoengineering, making it a project of great uncertainty.

Many scientists believed that since the progress of technology upon geoengineering is rapid this would result in new methods that would solve any initial disadvantages (Schelling (1996)). But the truth is that years have pasted and we haven't seen any great difference, at least for now. One of the issues that draw too much attention is a Schelling's (1996) argument which stresses that with the use of geoengineering we must take into consideration the fact that there are no geographical boundaries, no national regulations that can be implemented and finally there is no compulsory participation. In reality this is one of the most significant reasons why the implementation of geoengineering is considered risky.

Emmerling (2013) points out that "apart from the scientific and economic uncertainties, ethical considerations, moral issues regarding the manipulation of the climate, and issues in international law regarding unilateral actions in this field provide a strong barrier towards even proceeding in research in this field. The cancellation of the Stratospheric Particle Injection for Climate Engineering (SPICE) project in 2012 provides an example of the difficulties research faces in this field including due to public opinion or the governance of such projects". Public opinion can affect the decisions that must be taken in order for a geoengineering scheme to be implemented. This happens since most of the people dislike the idea of messing with climate and the environment so their fear is independent of the results of a cost-benefit analysis. So besides scientists' fear we must take into consideration the fear of the public.

Another problem that arouses with the implementation of geoengineering is the governance of such a scheme. Who gets to decide what the concentration level of carbon ought to be? Who gets to decide what the temperature ought to be? In geoengineering schemes governance plays a huge role cause through this way it will be decided if and under which circumstances will geoengineering be used, in what extent, from which countries and what will the cost sharing will be. All this topics are very important issues and every nation should consider the pros and cons unilaterally. Virgoe (2008) states that: "An examination of international legal instruments reveals none that would pose an insuperable barrier to geoengineering”. This means that we still haven’t form the necessary laws in order to coordinate any geoengineering project. This is considered to be a major drawback since geoengineering is a local action with a global impact. As Bengtsson (2006) argues “the artificial release of sulfate aerosols is a commitment of at least several hundred years”, pointing to the need for a durable governance regime. So nations must begin building useful international norms to govern geoengineering in order to assess its dangers and decide when to act in the event of an impending climatic disaster.

According to Emmerling and Tavoni (2012) “One of the core problems of SRM is that it’s not yet implementable”. By this they mean that the research that took place so long is only in theoretical basis and has not yet been in practice with real experiments. Major role in this drawback is the fact that if a nation decides to put in action SRM, because it’s inexpensive and fast, there is a big fear that this will do more harm than good not only to this single’s nation environment but worldwide. The fact that geoengineering can only delay and not eliminate the damages that carbon causes to climate is another reason for which some scientist are not very font of this method.

As many, Sterck (2011) states the harmful effects of geoengineering but it also takes into consideration the intergenerational issues that will emerge. In his paper he finds that “while current generations will anticipate the use of geoengineering by increasing their emissions, future generations will have to reduce their emissions, to bear the cost of sustaining geoengineering for centuries and to suffer from its negative side-effects". These indirect consequences raise disturbing intergenerational issues. As Sterck (2011) implies “The net benefit from geoengineering for current generations is positive as they may increase their emissions without engaging in costly abatement. For future generations, the situation appears to be much worse: as they inherit a higher stock of pollution, they may be compelled to implement geoengineering in order to prevent catastrophic climate damages and to avoid reaching “tipping points”. Consequently, future generation will have to support the negative side-effects of geoengineering, as well as to bear the full cost of geoengineering, which includes R&D investments as well as the capacities required for maintaining high levels of geoengineering for centuries”.

Another fear that is assumed is that “geoengineering will not be undertaken progressively” according to Sterck (2011). As a result there will be abrupt changes in climate that will cause unprecedented environmental problems. Sterck (2011) shows that "the optimal path of geoengineering use is characterized by a jump, which will in turn induce a sharp and sudden decrease in temperature. This abrupt temperature drop may prove to be particularly damaging for fragile ecosystems and vulnerable regions".

Goes *et. al.* (2011) are trying to give a suitable answer to the question that most of their colleagues asked: "What are scientifically sound, economically viable, and ethically defendable strategies to manage climate risks?" They commend that risks like the failure of sustaining aerosol forcing and the harmful impacts that SRM would have in the environment are being neglected. Moreover Manoussi and Xepapadeas (2013) say that bigger problems arise when we stop geoengineer the environment particular in the Earth's temperature. So according to them the continuing flow of geoengineering plays a significant role to the Earth's temperature stabilization.

A significant impact of geoengineering is that upon the hydrological cycle. According to Bala *et. al.* (2008) "insolation reductions sufficient to offset global-scale temperature increases lead to a decrease in the intensity of the global hydrologic cycle. This occurs because solar forcing (which includes methods that either block incoming solar radiation, or equivalently increase the planet's albedo) is more effective in driving changes in global mean evaporation than is CO_2 forcing of a similar magnitude". They also state that hydrological cycle is more sensitive in geoengineering schemes rather than changes in greenhouse gases. This implies that an alteration in solar forcing might offset temperature changes or hydrological changes from greenhouse warming, but could not cancel both at once.

Urpelainen (2012) believes that time can also be a negative factor. His argument is that "whereas emissions reductions can be mandated now, geoengineering techniques are only available in the future".

Finally it is important to realize that even though geoengineering may be a very promising project the negativities that creates are still many and the great of all, as we already have mentioned, is the uncertainty and the lack of control. Subsequently we will refer to scientists that support the implementation of geoengineering and to those that object.

SECTION 3

SCIENTISTS' RESEARCH

3. In favor or against geoengineering?

Judging from the existing bibliography someone may thing that the economic spectrum of geoengineering is an issue that has been studied for many years. However this is not true. Even though the idea of geoengineering was known, as we already have mentioned, there were not many scientists that have deal with the economic side of geoengineering. Schelling (1996) was one of the first scientists that deal with this issue. In his research he stressed out significant arguments many of which are still consider being applicable. One of his main arguments was that technological progress can quickly make our present analysis out of date. He pointed out that the facts that today appear to be problems in geoengineering it may soon be negligible. Many aspects of Schelling's statements were rather innovative for the time they were written. One of those statements is this one: "One thing that can be said for geoengineering is that it immensely reduces the complicatedness of what nations have to do internally to cope with greenhouse problems and what nations have to do internationally to cope with greenhouse problems". In fact this statement is very truthful, especially because of the cheap application of geoengineering. From his paper we can understand that, in general, Schelling (1996) was in favor of researching further geoengineering. Nevertheless he was not the only one. In what it follows we shall mention some of the scientists that remain in favor of geoengineering and who believe that geoengineering is possible to bring a relief into our environment.

One of the arguments that are still valid is against those who believe that the use of geoengineering will cause decrease in mitigation of greenhouse gases and specifically of carbon. According to Emmerling and Tavoni (2012): "Even under optimistic assumptions, the reduction of optimal mitigation effort is relatively small" when geoengineering is implemented. This means that the constant fear that geoengineering might cause the nations to emit more and stop mitigating is actually based on a false conjecture (Emmerling and Tavoni (2012)).

Another matter that scientists took into consideration was the results of a cost-benefit analysis. As Bickel and Agrawal (2011) state: “framing the use of geoengineering is critical to determining its cost-benefit” and according to them this is the reason for which some cost-benefit analysis do not show accurate results. Gramstad and Tjotta (2010) used a DICE model (Dynamic Integrated model of Climate and the Economy) in a cost-benefit analysis and they found that climate engineering passes the test. Moreover they found that “The cost of postponing climate engineering by 20-30 years is relatively low”. Recently the injection of reflective particles, principally sulfate aerosols, in the high-atmosphere (Crutzen (2006)), and the increase of the albedo of maritime areas by seeding and whitening stratocumulus clouds over the oceans (Salter *et. al.*, (2008); Latham *et. al.*, (2008)) were evaluated using modified DICE models (Nordhaus (2007); Bickel (2009); Goes *et. al.* (2011); Bickel and Agrawal, (2011)). All but Goes *et. al.* (2011) conclude that geoengineering is highly cost-effective. As a result it is believed by many that the negativity that geoengineering might have is insignificant in comparison to its positive effect in the environment.

But the positive arguments do not stop here. Another important issue that we must take into consideration is the fast action that geoengineering has, compared with abatement. This is why geoengineering is considered by many as an emergency strategy. Although geoengineering cannot resolve the underlying cause of climate change at least it can prevent temperatures from rising. So geoengineering may be able to “buy time” (Barrett (2008)). In order to show that geoengineering implementation can coexist with mitigation, Barrett (2008) analyze this argument and conclude that “the minimization of climate change risk can be accomplished through a combination of emissions reduction and R&D into new technologies that could help the environment such as geoengineering”.

In addition the scientific principles behind geoengineering technologies are well established. According to Moreno-Cruz and Smulders (2010) geoengineering is distinct from traditional climate change mitigation strategies (abatement, for short) due to three particular reasons: first, the effects of geoengineering are immediate (Mathews and Caldeira (2007)) while abatement is slow because it relies on the carbon cycle. Second, geoengineering sometimes has the connotation of fixing the climate change problem at zero (or very low) cost and thus making climate change irrelevant. Rather than reducing greenhouse gases emissions, geoengineering reduces the impacts of the concentration level of these gases in the atmosphere. Third, geoengineering is much less costly than abatement and a single country could easily undertake enough geoengineering to protect the entire planet against the damage from global warming (Keith and Dowlatabadi (1992), Crutzen (2006), Blackstock *et.al.* (2009), Shepherd *et.al.* (2009)). Research has shown that the major disadvantage of mitigation is the big expense of its use which leads to free riding. This is why geoengineering is supposed to be a more convenient method since it's inexpensive and can be undertaken by a single country.

Moreover in Moreno-Cruz and Keith (2012) paper we come close with an attempt to minimize "the expected total costs (abatement and SRM costs) of managing climate change". They found that "even modest reductions in uncertainty about the side effects of SRM can reduce the overall costs of climate change in the order of 10%". This means that uncertainty upon geoengineering results plays a crucial role in the overall outcome.

Another reason for which geoengineering is thought to be better is the inertia that carbon climate system has. Inertia means that there is a lag between climate's response and the emission that mankind emit. Implementing SRM has as a result a quick effect in the climate, in which scientists base their hopes. Moreno-Cruz and Keith (2012) state that " the signal advantage of SRM is its quick response: even if damages from SRM are substantially high, it is still valuable to have SRM available, as a complement to abatement measures, in case the climate sensitivity is high".

Furthermore Moreno-Cruz and Keith (2012) numerical results suggest that the lower the side-effects of geoengineering and the higher its effectiveness, the lower will be the mitigation effort in the first stage. Moreover, geoengineering will be more likely to be used if the climate sensitivity is going to be higher. This illustrates the insurance effect of geoengineering. Without SRM, the existence of high-consequence low-probability climate impacts, combined with the irreversibility of emissions, may force very high levels of abatement and hence high costs. Moreno-Cruz and Keith (2012) conclude saying that" SRM is valuable for managing climate risk, not because of its low cost, but because it can be implemented quickly if we discover that climate impacts are high".

On the other hand there are scientists who strongly disagree upon the implementation of geoengineering. So, while there are many who insist on believing that the implementation of geoengineering is cheap relative to mitigation (Bickel and Agrawal (2011), Moreno-Cruz and Smulders (2010), Smith and Rasch (2012), Gramstad and Tjøtta (2010), Moreno-Cruz and Keith (2012)) there are some who deem that if we take into consideration all the impacts that geoengineering has then, in reality, is too costly (Goes *et. al.* (2011), Klepper and Rickels (2012)).

Furthermore as indicated by Weitzman (2013) geoengineering is also associated with an important externality which is different from the free rider externality associated with climate change. Weitzman calls this externality the free driver externality. The source of this externality is the fact that, because geoengineering is relatively cheap, it can be undertaken unilaterally by one country which is not willing to incur the cost of mitigation. This action however is very likely to generate potentially very large costs to all other countries. Thus while the private costs of geoengineering are low, the potentially very high social costs of geoengineering are spread among all countries.

Sterck (2011) is one of the scientists that support the pessimistic side about the results that geoengineering will have in the environment. Specifically he doubts the ability of geoengineering to help the environment and he considers the implementation of geoengineering as the reason that will cause the reduction of abatement. Also Emmerling's (2013) results suggest that "for the time being, geoengineering does not warrant to be taken as a reason to significantly delay abatement effort from an economic point of view, even under optimistic scenarios about its feasibility and acceptability". He finds that "uncertainty provides a strong argument for abatement as opposed to a "wait and see" policy relying on potential large scale geoengineering in the future, but does not rule out the possibility of deploying geoengineering in the future. This 'flat' relation between initial abatement and GE for a large parameter set provides an argument to rely more on mitigation today".

Finally there are some who consider the implementation of geoengineering extreme. For instance Morrow *et. al.* (2009) describe the possibility of geoengineering testing being compared, historically, with that of nuclear weapons testing near populated areas and poor rural African-Americans subject to medical experiments.

Thinking all the above, what surely can be said about geoengineering is that it divides people's opinions. For example there are many who believe that the implementation of geoengineering would help the environment, as we mentioned above, and those who state that greenhouse gas accumulation will be higher in the case of geoengineering (Manoussi and Xepapadeas (2013)). So if we want for geoengineering to be part of an optimal climate strategy then the environmental impacts must be sufficiently low compared with the effect it has on reducing "traditional" climate damage.

Nonetheless, even if research shows that the implementation of geoengineering will only bring benefits, still in that case there is another problem that nations must solve. The powerlessness of nations to reach accordance and to form coalitions still exists. In the following section we will examine the study that has been done upon international environmental agreements and specifically under the option of geoengineering.

SECTION 4

International environmental agreements from the angle of geoengineering

4. International cooperation, is it possible?

As Bracmort and Lattanzio (2013) state: "International agreements have the capacity to codify normative standards for an emerging science on an international level, create institutions for global enforcement and research, and provide a framework under which transparency can be enhanced, development modifications can be made, and future multilateral discussions can occur". However, nations are trying to find a technically, economically, socially, and politically feasible solution at a domestic level, not worldwide. The main question in the case of international environmental agreements is whether countries can voluntarily form an agreement to protect the environment. History has shown that if agreements are too strict then nations either refuse to join or they change the conditions of the agreement in order to make them hazier.

At first when geoengineering option was not so known, attention was upon the reduction of domestic emissions in each country. Scientists were eagerly trying to find a way so as countries to form a multilateral coalition upon the protection of the environment through cutting down their emissions. The problem was free riding which was causing countries to avoid cooperation. The free rider problem is when the private marginal cost of taking action to protect the environment is greater than the private marginal benefit, but the social marginal cost is less than the social marginal benefit. The tragedy of public goods like the protection of the environment is that, because no country owns the environment, each country has an incentive to utilize its resources as much as possible and as a result without governmental involvement, the environment is overused and finally overpolluted. Since there wasn't, and there isn't, any authority to force countries to cooperate in order to achieve an environmental goal the problem of cooperation still exists.

According to bibliography there are three main approaches in order to form a coalition of countries. First there is the case where small group of countries are searching a way in which they will reduce their emissions by making other countries to sign the agreement through selffinancing welfare transfers (Barrett (1994), Barrett (1997)). Second there is the case where externalities are being taken into account and so countries in order to reduce their emission they share their costs so that each country is better off with cooperation (Chander and Tulkens (1992), Chander and Tulkens (1994)). Finally there is the issue of linkage where the environmental agreement is linked with another issue so as to be sustainable (Cezar and de Zeeuw (1996)).

According to Carraro and Siniscalco (1993) for an agreement to be sustained we must have profitability and stability. To form a stable coalition though, we must take into account marginal benefits and marginal costs (Barrett (1994)). According to Barrett's (1994) results an international environmental agreement will work only if the gains from the agreement are modest or if the number of participants is very small (a few countries). As we already have mentioned the reason why this occurs is the free riding problem. According to Millard- Ball (2012) the free rider problem is based to the inability of countries to take into consideration the full spectrum of benefits that abatement brings to the world. As he says: "Greenhouse gas abatement by a country brings external benefits to other countries, yet these external benefits are not considered by a self-interested, rational nation. Thus, aggregate abatement is suboptimal". If there was an external forcer then, "international environmental agreements (IEAs) could help mitigate this underabatement. For example, a treaty under which every nation agreed to abate until its marginal cost equaled the global marginal benefit would yield the efficient outcome" says Millard-Ball (2012). Unfortunately such an external forcer does not exist.

All the above take place when we have in mind to reduce carbon emission i.e. to abate or mitigate. In the case of geoengineering things are a bit different. As Bracmort and Lattanzio (2013) say: "it can be difficult, particularly when an international situation is new and evolving, to develop international consensus on a set of norms, let alone commitments, given the cultural, political, environmental, and economic diversity of the world's nations. Consequently, the process of developing these norms may be time-intensive and carry the risk of stalemate". This is mostly why countries would be more willing to agree upon research and deployment activities rather than something more specific in the case of geoengineering. Also it is difficult to monitor and enforce effectively the implementation of international environmental agreements. The difference from abatement is based upon the fact of unilateral implementation. Though in the case of abatement we have the free riding problem, in the case of geoengineering we meet the free driver problem (since geoengineering can be applied inexpensively) which leads to unilateral implementation of geoengineering. But taking into consideration the above analysis in the previous sections we understand that the impacts of geoengineering even in the case of unilateral implementation, except the fact that they are global, they are also unpredictable. We realize that there are two different externalities involved in the climate change problem. As Weitzman (2013) states "If the first externality founders on the free rider problem of under- provision, then the second externality founders on what might be called the free driver problem of overprovision. If the first externality is the mother of all externalities, then the second externality might be called the father of all externalities. These two powerful externalities appear to be almost polar opposites, between which the world is trapped". This causes major complications upon the formation of an IEA (International Environmental Agreement).

As research has shown since geoengineering only stalls the global warming problem and does not solve it, then it can never fully substitute for mitigation. Scientists came with the idea of a mixture of both abatement and geoengineering as a possible solution. Barrett (2006) says that "our approach to treaty design should be strategic". In particular the treaty should be "one that includes collective financing of R&D and the adoption, in key sectors, of breakthrough technologies exhibiting increasing returns. Such a system may not be fully cost-effective in the usual sense of that term, but this may be the price that must be paid to sustain greater cooperation" as he proposes. This occurred because of the lack of geoengineering to solve the coordination problem that creates. The coordination problem is a situation in which the interests of agents coincide, and the aim is to try to reach an outcome in which those interests are satisfied. Barrett (2013) believes that "rather than cooperate to limit emissions, countries need only coordinate to avoid catastrophe". He proposes that while the mitigation game is one of cooperation, the solar geoengineering game is one of coordination in which the only relevant decision is how to divide the costs of SRM. Under these circumstances, climate treaties can sustain the efficient outcome and this happens because "nature herself enforces an agreement to avoid catastrophe".

If we consider geoengineering as the method that will bring the needed relief in our environment then the only matter that we must investigate is finding a way through which nations will collaborate and agree on implementing it. But research has shown us that as the members in a coalition grow, it becomes much harder to conclude in a unanimous agreement. Research upon the IEA's and their application in environmental worldwide coalitions has shown that the achievement of such a project is rather difficult, if impossible, due to free riding. Apart from global impacts, an additional reason for which free riding is observed is due to the difference upon national interests. By this we mean that geoengineering may be interest some countries like Russia, China, Canada and some not, like countries in Asia and Africa.

Because of lack of institutional arrangement there is always the fear of unilateral implementation of geoengineering. MacCracken (2006) argues that "it seems rather unlikely that a global coalition of nations could be kept together to sustain such a diversion of resources over such a long time-frame. It is slow and difficult to get agreement on effective action through a universal process, even in a crisis".

Moreover as Ricke1 *et. al.* (2013) state: "if a nation decides to deploy geoengineering in an extensive scale then it is inevitable to avoid interference from other powerful nations". However this interference can conclude in the formation of small coalitions between countries that put up with the same climatic consequences and have the same interests. Since there are different strategic incentives Ricke1 *et. al.* (2013) state that there is a possibility for a coalition to be formed and besides the fact that it might be small it can be powerful enough to deploy geoengineering. Furthermore they find that "coalition members have incentives to exclude non-members that would prevent implementation of solar geoengineering at a level that is optimal for the existing coalition". They mark that the above incentives are way different from those in the case of emissions reduction for the avoidance of the phenomenon of free riding. Also support the idea that in order to have great participation in the global coalition we can use either "credible threats of reciprocation" or side payments. In their paper they find that in the case of geoengineering an exclusive, rather than open membership, coalition game will form. Furthermore their results indicate that although "multiple coalitions are likely to appear around different preferred amounts of solar geoengineering", only one amount can be implemented that affects the global outcome as a result only one coalition with the majority power share is implemented. The formation of this coalition offers an increase on "benefits from geoengineering by 1–7% over what they would achieve in the grand coalition that would form in the absence of exclusion". In addition they state that the use of side payments through intracoalition transfers ensures that there always be formation of an exclusive coalition and that this will guarantee no rapid climate changes.

Another way through which we can make sustainable treaties is through trade sanctions. If we put trade sanctions into the game then our treaties become more powerful and are not prone to free riding (Barrett (1997)). Trade sanctions are a more promising enforcement mechanism and have been incorporated into several proposals for a successor treaty to Kyoto (Aldy *et. al.* (2003)). In the case of climate, however, the losses to enforcer countries through a potential trade war may render the punishment non-credible.

The standard model of a self-enforcing international environmental agreement has shown that it's impossible to have an international coalition in reducing greenhouse gas emissions. Barrett (2005) suggests a method of punishments in order for the IEA's to be sustained and include full participation and compliance. Participating nations must see a gain in actually applying punishment; otherwise their threat of retaliation is not credible. These punishments in order to accomplish their goal should be credible, rigorous and should not need any countries consent. All the past treaties like for example the Kyoto Protocol was unsuccessful in one or more of the above. This research points toward modifications upon environmental treaties.

Barrett's (2013) results show that "when this model is modified to incorporate a certain threshold with catastrophic damages, treaties can become highly effective". This also applies in the case of geoengineering. According to Barrett (2013) "if there is a threshold that triggers climate catastrophe and its existence is known, then having benefits from the avoidance of the climatic catastrophe bigger than costs, can lead to a coordination between countries so as to avoid the surpass of the threshold". This means that there is the ability for a collusion to hold if critical information is known such as the above threshold. Another significant result from Barrett's paper is the fact that "the uncertainty of the catastrophe's impact does not affect the countries' coalition but the uncertainty of the threshold can have "critical" results. This means that we should only consider the uncertainty of the threshold in order to stabilize countries' coordination and lead them into an IEA.

However there are some that oppose to the idea that geoengineering's coordination problem can be solved easily. For example Moreno-Cruz and Smulders (2010) results show "that geoengineering worsens existing coordination problems in climate change policy. Moreover, if a single agent overestimates the net world benefits of geoengineering, it might introduce it at huge cost for the world economy". Weitzman (2009) has drawn our attention to ''uncertain catastrophes with tiny but highly unknown probabilities", showing that ,if the probability of ever larger catastrophes does not fall faster than welfare losses increase as we venture deeper into the tails of the probability density function, then the expected gain from a policy to reduce emissions will be infinite. Under these circumstances, policy should do everything possible to reduce emissions as quickly as possible, even though doing so cannot guarantee that catastrophe will be avoided. He calls this result, appropriately enough, ''the dismal theorem''. Nordhaus (2009) argues, to the contrary, that any conceivable catastrophic outcome can be avoided by policy, but that doing so requires ''solving the global public goods problem by gathering most nations together to take collective action''. Weitzman does not address the collective action aspects of this challenge, but his theorem should carry through in a decentralized setting. If it pays the world as a whole always to devote more resources to reducing a threat that cannot be eliminated, no matter the cost, then it should pay individual countries always to devote more resources to reducing the same existential threat, even when the benefits of doing so are widely dispersed. That is, under Weitzman's assumptions, coordination should be unnecessary. Every country should want to put its economy on a ''climate war'' footing, irrespective of whether other countries join them in this effort.

Since there is heterogeneity in the way that the environment will respond to geoengineering there would be heterogeneity in the level of implemented geoengineering. Rickel *et. al.* (2013) state that "given the very low direct costs associated with solar geoengineering, the only reason to cooperate in such a game is to gain political viability. In this type of exclusion game, only players that prefer to form a coalition with each other are able to do so, and players that are not wanted in a coalition cannot enter". The key issue in order to solve the free driver problem is governance, cause without it geoengineering could be transformed in a major global threat. Weitzman (2013) proposes the implementation of a social-choice architecture based on a supermajority voting rule. The free driver problem accrues from the difference upon the implemented amount of geoengineering among countries. So he uses the above rule in order to reconcile these differences. He concludes that "a relatively simple supermajoritarian rule overcomes the free-driver externality to obtain the socially optimal solution". But the governance problem is also stressed from Urpelainen (2012). He points out that the threat of an impending geoengineering war may conclude to an emissions reduction.

In the bibliography upon geoengineering and its relation with international environmental agreements we encounter a vast variety of models. Urpelainen (2012) uses a game of complete information with two symmetric countries (A and B) which first decide on mitigation and afterwards on geoengineering. Considering mitigation as a "profitable public good" and geoengineering as a "mixed bag" which offers both advantages and disadvantages he puts first countries to decide emissions Ei [0, ∞) and then to decide the amount of geoengineering Gi [0, ∞) that they will use. Its country has a payoff which is the following:

$$U_i = B \cdot \ln(E_i) - C \cdot (E_i + E_j - G_i - G_j)^2 - G_i^2 - x \cdot G_j^2 .$$

The symbols above are:

B>0, economic benefits from fossil fuels which is decreasing in scale [its reduction is determined from ln(Ei)]

C>0, damage from global warming which is increasing in total emissions [Ei+Ej] and decreasing in total investments in geoengineering [Gi+Gj]

x, negative externality to country j from geoengineering projects of country i.[For x<0 the negative externality to country j is less costly than domestic implementation, for x>0 the opposite is true].

In order to conclude in a solution (subgame-perfect equilibrium) Urpelainen (2012) uses backward induction. First he takes first order conditions and he finds:

$2C \cdot (E_i + E_j - G_i - G_j) = 2G_i$ [Left side is marginal benefit of increasing slightly geoengineering and right side is marginal cost]. As Urpelainen (2012) says: "this expression shows that each country i fails to internalize the impact of geoengineering on country j in at least two ways. First, it ignores some of the beneficial effect of geoengineering on temperatures. Second, it ignores the damage inflicted by geoengineering on the other country. This formulation captures the governance failure that geoengineering may entail (Barrett (2008), Victor (2008))". Taking first order conditions and creating a linear system of two equations with two choice variables Gi and Gj we have the solution below:

$G_i^* = \dfrac{C \cdot (E_i^* + E_j^*)}{1 + 2C}$. With the above solution we can understand that geoengineering is increasing both in past emissions and the cost (C) of global warming.

Continuing his method he proceeds in first period in order to find the equilibrium emissions level. Maximizing country's j payoff with respect to Ei and taking Gi and Gj as granted from the analysis above he finds:

$\dfrac{B}{E_i} = \dfrac{2C(1 + C + Cx)}{(1 + 2C)^2}\left(E_i + E_j^*\right)$ [Left side is the benefit from increasing emissions and right side is the cost of doing so which is increasing in total emissions Ei+Ej]. Solving the system of two equations we have:

$E_i^* = \dfrac{\sqrt{B \cdot (1 + 2C)^2}}{2\sqrt{C \cdot (1 + C + Cx)}}$. The solution shows that equilibrium emissions increase in benefits (B), decrease in cost (C) and decrease in damage x which is caused from the other country's geoengineering. The last means that country i reduces its emissions when geoengineering is potentially harmful to country j. This happens because if country i decides to act differently then it will cause country j to geoengineer very much and as a result country i will harm herself. Finally Urpelainen (2012) finds the equilibrium geoengineering investment, $G_i^* = \dfrac{C \cdot \sqrt{B}}{2\sqrt{C(1 + C + Cx)}}$, by substituting the equilibrium emission in the equation $G_i^* = \dfrac{C \cdot (E_i^* + E_j^*)}{1 + 2C}$. As a result he concludes that Gi increases in B (emissions benefits) and C (cost of global warming) and decreases in x (damage inflicted on country j). As Urpelainen (2012) poses "the equilibrium analysis shows that as geoengineering begins to produce negative externalities for foreign countries, the incentive to mitigate global warming increases". This means that serious impending side effects of geoengineering can help towards this direction. As a result more countries would want to abate and fewer countries would want to geoengineer. He proposes either a “preventive” action (emissions reduction) or a “treatment” action (geoengineering). He states that “the core insight into the strategic analysis is that, as long as treatment strategies produce negative externalities, a good case can be made for favoring prevention”. It is very important to consider that the amount of mitigation that will be implemented today will determine, to some degree, the expectation of geoengineering.

The same statement is been supported also from Millard-Ball’s (2012) paper. He shows that “the credible threat of unilateral geoengineering may instead strengthen global abatement and lead to a self-enforcing climate treaty with full participation”. As he continues “geoengineering may provide a punishment that is severe, credible and does not require ex-ante consent”. He bases his argument upon his research which is relative to Barrett’s (1994) and Barrett’s (1995) papers which use the simple non-cooperative game “to model participation and compliance in an international environmental agreement”. Millard-Ball’s (2012) game has four stages in comparison to Barrett’s. In the first stage countries choose whether they will participate on an IEA or not, in the second stage those that have formed an IEA decide their abatement level jointly in order to maximize their collective welfare (Stackelberg leader), afterwards the non signatories choose their abatement level which maximizes their own welfare and finally it is decided whether or not to geoengineer. The problem starts from the fact that IEA’s can increase abatement but only few countries form such a coalition, resulting in a much lower levels of socially optimum abatement. In his model Millard-Ball (2012) assumes N identical (symmetric) countries from which the ones that form an IEA fully comply. The payoff of its country is:

$$\pi_i = B(Q) - C(q_i) + G(z_i, Q) - D(z_{-i}, Q)$$

$$q_i \geq 0,\ \ Q = \sum_{1}^{N} q_i\ ,\ z_i \in \{0,1\}$$

, where

Q is aggregate abatement

B(Q) are the benefits from aggregate abatement and are increasing in total abatement

C(qi) is the cost of country i for her abatement qi and is increasing in a country's own abatement

G(zi,Q) are the net benefits of country i from geoengineering (including side effects any cost of deployment to country i) and are decreasing in abatement

zi is a binary variable (takes 1 for geoengineering deployment from country i and 0 otherwise)

D(z-i,Q) is the impact if another country except i geoengineers (then z-i=1) and can be negative. Also whether a country will geoengineer depends from her only in contrast to the impact of another country's geoengineering which is depended on other countries' decision. As for geoengineering impacts Millard-Ball (2012) considers them to be identical across countries [G(1,Q)=-D(1,Q)] which means there are no asymmetric benefits between countries. As Urpelainen (2012) uses backward induction so does Millard-Ball (2012).

First Millard-Ball (2012) starts with the fourth stage of the game in order to see whether geoengineering will be deployed and from which countries. So countries will either play zi=1, if G(1,Q)>G(0,Q) or zi=0. The country's expected payoff is:

$$\pi_i = B(Q) - C(q_i) + \frac{1}{N}G(1,Q) - \frac{N-1}{N}D(1,Q) \text{ if } G(1,Q) > G(0,Q) \text{ ; otherwise, } \pi_i = B(Q) - C(q_i)$$

. In the next stage he solves for non signatory abatement decisions and he finds:

$$\max_{q_i} \pi_i = B(Q) - C(q_i) + \frac{1}{N}G(z_i,Q) - \frac{N-1}{N}D(z_{-i},Q)$$

, where q_i^n is the abatement decision of each non-signatory. Moving to the second stage signatories j=1,2,…,k choose q_j^s to maximize their collective surplus and maximize the below:

$$\max_{q_j} \sum_{j=1}^{k} \pi_j = kB(Q) - \sum_{j=1}^{k} C(q_j) + \frac{k}{N} G(z_j, Q) - \frac{kN-k}{N} D(z_{-j}, Q)$$

. Finally we get an equilibrium k* if

$$\pi_s(k^*) \geq \pi_n(k^*-1)$$
$$\pi_n(k^*) \geq \pi_s(k^*+1)$$

hold. Millard-Ball (2012) concludes in two propositions. First he proposes that "a credible threat of geoengineering can increase abatement levels" and also that "a credible threat of geoengineering can promote full participation in an IEA". He states that if

$$B(\tilde{Q}) - C(\tilde{q}_i) + \frac{1}{N} G(1,\tilde{Q}) - \frac{N-1}{N} D(1,\tilde{Q}) > B(Q^g) - C(q_i^n)$$
$$\tilde{Q} = Q^g - (q_i^n - \tilde{q}_i)$$

does hold then any non-signatory will reduce abatement (Qg is the aggregate abatement in the absence of a geoengineering option and $\tilde{q}_i$ the reduced abatement level). He finds that if "geoengineering is sufficiently scary, i.e., net damages from geoengineering plus the foregone abatement benefits outweigh the cost savings from reduced abatement" then the above does not hold. Moreover he assumes that if k*=N which means that all countries participate in IEA and that the level of abatement is such in order to prevent geoengineering and is devided equally among countries:

$$G(1,Q^g) = G(0,Q^g)$$
$$q_i^g = Q^g / N \ \text{for } j = 1,2,\ldots,N$$

, then as Millard-Ball (2012) says" any reduction e in the deviating country's abatement will lead to the deployment of a geoengineering scheme. Then no country can gain by deviating, provided that the benefits from deviating are less than the costs imposed by geoengineering". Which means that there is equilibrium when:

$$C(q_j^g) - C(\tilde{q}_j) + \frac{1}{N} G(1,\tilde{Q}) - \frac{N-1}{N} D(1,\tilde{Q}) \leq B(Q^g) - B(\tilde{Q})$$
$$\forall\, \tilde{q}_j \in [0, q_j^g] \quad \tilde{Q} = Q^g - (q_j^g - \tilde{q}_j)$$

Nevertheless there are many that support that such course of action still remains impractical. Bodansky (1996), states that it may be impossible to secure credible commitments from all countries to refrain from unilateral geoengineering. This is why some like Finus et. al. (2009) suggest that multiple agreements among countries with similar interests may be more effective than a single global. As we have mentioned in the previous section there are still scientific papers like Manoussi's and Xepapadeas's (2013) that show the exact opposite results from Millard-Ball's research. Their results suggest that "when geoengineering is a policy option, the steady state accumulation of GHGs is higher relative to the case where geoengineering is not an option". A surprising result is that, as Manoussi and Xepapadeas (2013) say, "in the context of our model, cooperation implies more mitigation and less geoengineering, while noncooperative behavior implies less mitigation and more geoengineering. This result suggests that if international cooperation to reduce GHG emissions cannot be reached and countries move to unilateral actions, geoengineering rather than mitigation is the policy to be expected".

However the question for many is why should we make so much fuss upon international cooperation through environmental agreements? Well the gains that occur are many as we saw in Section 1. But there is also an additional reason that we haven't still reveal. The fact that anyone can enter in a coalition for geoengineering means that the world temperature could be controlled and stabilized in a logic degree and not according to the preferences of some specific and powerful nation. This means that our environment and its course will not be monopolized and as a result we will have worldwide benefits. In addition Van der Ploeg and De Zeeuw (1992) state that "International policy coordination leads to higher emission charges and consequently lower levels of production" and in its turn lower levels of production leads to "lower levels of pollution".

SECTION 5

Conclusions

5. Review and proposals

Environmental problems are issues that draw attention immediately due to their extended influence. One of the most important environmental problems, if not the most important, is global warming. The inability of nations to control carbon emissions through mitigation has brought out to the surface the use of geoengineering as an emergency strategy. Nonetheless research has shown that the promising face of geoengineering might not be so promising after all. As we saw from the reviewing literature geoengineering presents difficulties because of its unpredictable results, its lack of actual deployment in the real world and finally its inability to be implemented through a unanimous coalition of countries with the use of an environmental agreement. However we cannot ignore the fact that in the future with more modifications and technological progress it may be possible for geoengineering to bring in positive results. There are many proposals that one can make in order for geoengineering to be an effective method to combat global warming. In what follows we will refer to scientific proposals for the solution to the above geoengineering problems.

It would be premature to assume that geoengineering will save the climate, but equally premature to assume that geoengineering will destroy the planet. For this reason it would be beneficial to deploy an active research program and to stop the harmful expansion of the implicit taboo against geoengineering research. Scientist's beliefs and standpoints influence the possibilities of realizing climate engineering and may create great political costs. It is imperative to focus upon early exploration of the technological, environmental, political, social and regulatory issues raised by geoengineering, to maximize the chances of good, science-based multilateral decision making. Also research upon local and national laws might still be needed to address aspects of geoengineering that could not be addressed on an international scale.

Upon the technological and environmental issues further scientific research on the consequences of geoengineering is necessary and a sharp focus on the negative externalities and their distribution across countries would be particularly welcome. Some of the things that must be taken into consideration is the sea level rise, the precipitation patterns etc. We must carefully review the magnitude and asymmetries of negative externalities from geoengineering, because these negative externalities determine how strict the legal constraints on geoengineering should be.

Up till now, no treaty has been proposed with the intent of addressing the full spectrum of possible geoengineering activities. Severe governance issues are raised by geoengineering implementation and soon must be warrant that these issues will be addressed by the international community long before the problem becomes dangerous. We will also need advisory commissions with public participation and definitely we will need an oversight mechanism which will be transparent and liable. A new protocol should be created that specifies whether and under what conditions geoengineering should be allowed or possibly even required, and how the costs of any efforts should be shared. The governance institutions require ensuring equity among countries that implement geoengineering and climate mitigation. This means that a concrete governance structure with specific rules concerning how to make final decisions about geoengineering levels that differentially impact parties having different interests is needed. Otherwise, with a free-driver externality, we risk paralysis and conflict.

But designing an effective political and economic strategy to control climate change will require the use of social sciences to analyze how to harness our economic and political systems to achieve our climate goals effectively and at low cost. Also we should identify precisely how geoengineering can be designed to generate differential benefits and costs to enable it to act as a credible threat. This will give us the chance to form sustainable agreements. Indirect costs, such as penalties or sanctions should also be considered in order to form bigger coalitions. A regime upon geoengineering will need to be designed in a way which ensures a geoengineering intervention is appropriately calibrated and managed within a portfolio of climate change mitigation and adaptation measures, while attempting to minimize the moral hazard problem. A geoengineering regime would therefore need to combine durability with the ability to take timely decisions which respond to changing circumstances and knowledge.

Concluding we understand that still remains too much work upon the field of geoengineering before its implementation in the real world. The key question is whether serious consideration of geoengineering will begin now, or only once highly disturbing climate change is appeared.

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