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Geoengineering Biodiversity: Study to Access Feasibility of Geoengineering Techniques on Biodiversity

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Author's contribution

The sole author designed, analyzed and interpreted and prepared the manuscript.

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ABSTRACT

As Earth continues to experience increased global warming, biological species on Earth are pushed to constantly modify and adapt to the changing Earth's climate in order to survive. This environmental pressure might push some of the more fragile species toward the brink of extinction thus human interventions are deemed necessary to minimize the current and future impacts of climate change. Current interventions include mitigation through international policies and regional laws by reducing anthropogenic outputs into Earth's climate system as well as conservation efforts to slow down extinction rate. In this paper, we will discuss how geoengineering can be added into one of these human interventions to reduce impacts of climate change on Earth's biodiversity. Geoengineering might provide immediate and simple solutions to current climate problems, however, only few researches have been conducted to study impacts and feasibility of geoengineering on life on Earth. Discussion on the feasibility and impacts of geoengineering on biodiversity will be assessed for two main techniques of geoengineering; carbon dioxide removal (CDR) and solar radiation management (SRM). From these two techniques, afforestation, which is one of CDR methods was selected as this method provide viable and sustainable form of geoengineering towards biodiversity.

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1. INTRODUCTION

Climate change has been a continuously ongoing issue that governments and international bodies have yet to find the feasible permanent solutions. Since the last few decades, Earth has experienced some of the worst climate variability, which not only affected humanity, but also the resiliency of other biological species on Earth. Diffenbaugh and Field [1] argued that over the past few decades, biological species on Earth experienced increase pressure to undergo modifications in their genotype as well as phenotype through a process of adaptive radiation in order to continue surviving to compensate extreme climate variability on Earth.

Intergovernmental Panel on Climate Change (IPCC) reported that with current trajectory of global annual and cumulative emission of greenhouse gases (GHGs), Earth will experienced an increase of 1.4℃ to 5.8℃ in global mean temperature within the next few decades [2]. One study indicated even higher global mean temperature rises of 4℃ to 8℃ towards the year 2100 [3]. In addition, IPCC projected that current carbon dioxide (CO_2) concentration, which is often use as an indicator, will also observed an increase with the next decades, ranging between 478-1099 parts per million (ppm) by the year 2100 [2]. Projected increase of CO_2 concentration will not only add burden on current GHGs concentration in the atmosphere but is deemed sufficiently enough to cause major ocean acidification leading to acceleration of another great extinction of major marine species as well as incur significant losses of ocean resources, which may be absolute detrimental to countries that are highly-dependent on these resources [4,5].

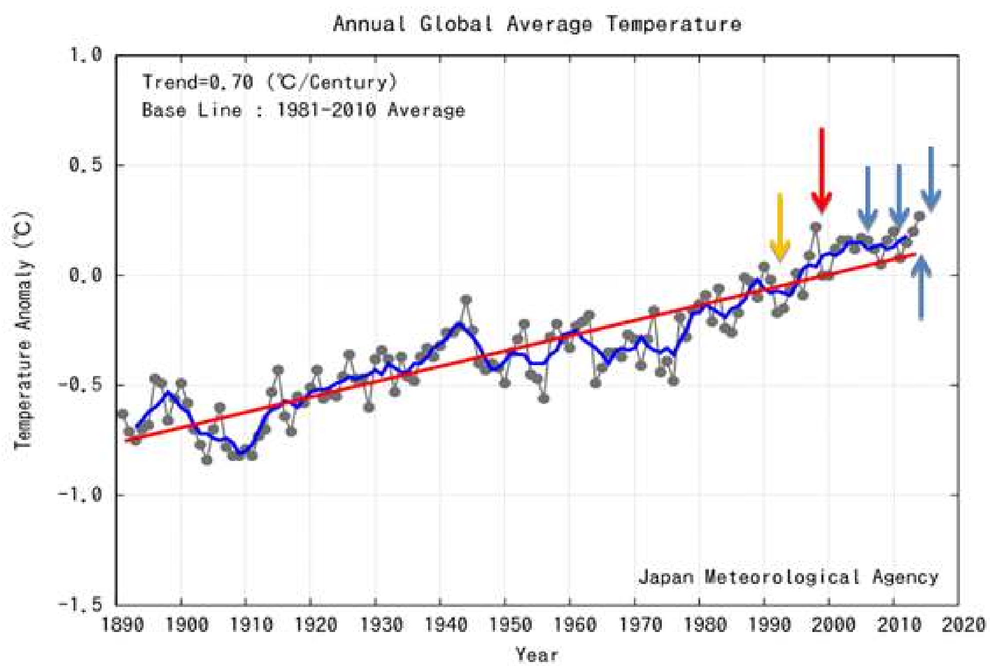

Fig. 1. Annual Global Average Temperature from 1890 to 2014. Recent temperature anomalies are calculated using deviation of baseline (1980-2010) average. Arrows (red and blue) represent five warmest years on record (1998, 2005, 2010, 2013, 2014). Red arrow indicates warm year due to 1998 ENSO. Orange arrow indicates cooling after Mount Pinatubo eruption in 1991. Black line represents actual temperature anomaly based on yearly record. Blue line represent average 5 years running mean of temperature anomaly, and red line represent long-term trend linear anomaly of annual global average temperature. Dataset provided by Japan Meteorological Agency [6]

Fig. 1 illustrates the global average temperature trend since 1890. An overall rising trend is observed throughout the dataset and through history only one of Earth warmest year have been attributed to ocean-atmospheric coupling feedbacks such as El-Nino Southern Oscillation (ENSO) [7]. Kahn [7] further added that majority of Earth warmest years on records were due to anthropogenic global warming. Additional data from Japan's meteorological agency support Kahn's observations that Earth four out of five warmest recorded years are within the last 10 years and does not corresponded with ENSO or other natural related forcing.

To address the rising trend of temperature and CO_2 concentration, major international bodies and some regional governments have directed mitigation procedures to reduce current and future anthropogenic burden on climate and biodiversity. These include implementation of international policies, protocols, conservation efforts, and regional laws directed towards managing localized anthropogenic activities and ensuring biodiversity resiliency [8,9].

Suggested mitigation procedures have shown some level of effectiveness throughout the implementation stage [8,9]. However, with continuous trending in global economies, increasing population size, and increasing need for additional resources can provide barrier to the successfulness of the suggested mitigation procedures in the future [8,9]. The Royal Society's report on geoengineering (2009) stated that unless all mitigations procedures are deemed reliable and able to exhibit a highly successful implementation, further interventions are needed to address the increase impacts of climate change on humanity as well as biodiversity.

2. METHODOLOGY

In this paper, we will discuss the subjects of biodiversity and geoengineering through selections of scientific articles, news, and proceedings which are related and relevant to our study. Datasets and tabulations of information generated are through the use of these references indicated throughout the paper.

3. CONCEPT OF GEOENGINEERING

The concept of geoengineering has been around since 1965 when then President of United States, Lyndon Johnson, through his scientific advisors, suggested in altering the earth's surface using reflective particles in order to reflect additional sunlight, which at the time caused by the increase in carbon dioxide concentration in the atmosphere [10]. As we continue to experience highly variable climate, increasing global warming, and further biodiversity loss, human manipulation of climate is deemed feasible for Earth to be habitable and perhaps resilience as we progress towards the future.

Geoengineering of climate can be divided into two main components consisting of carbon dioxide removal (CDR) techniques as well as solar radiation management (SRM) techniques [8]. These two techniques posed unique types of interventions in which CDR intervened by removing greenhouse gases particularly CO_2 from the atmosphere and SRM intervened by modifying Earth's albedo through offset of GHGs and the use of reflectors [8,9]. Table 1 illustrates the main methods of CDR and SRM techniques.

4. DISCUSSION

For this particular article, we will be selecting some of both CDR and SRM methods which would likely to give impactful result on biodiversity resiliency. In addition, we will also evaluate the feasibility of each method chosen and rate them on how well these methods help in the conservation of biodiversity. We hypothesized that with human control climate

Table 1. Suggested methods of CDR and SRM techniques of geoengineering. Table summarized complete methods outlined by The Royal Society's report on geoengineering. Congressional Research Service's report (2013)

Techniques	CDR	SRM
Methods	▪ Ocean fertilizations ▪ Carbon capture and sequestration ▪ Afforestation ▪ Enhanced weathering	▪ Enhanced albedo (surface and cloud) ▪ Aerosol injection (preferably hydrogen sulphide, H_2S and sulphur dioxide, SO_2) ▪ Space reflector

through these selected methods, much of Earth's biodiversity of both terrestrial and marine will be conserved and the feasibility of the next great extinction can be reduced. Methods chosen are (1) ocean fertilizations and (2) afforestation from CDR technique as well as (1) enhanced albedo and (2) aerosol injection from SRM technique.

4.1 CDR Option 1: Ocean Fertilization

Ocean fertilization uses nutrients such as iron, phosphorus, and nitrogen to encourage the growth of phytoplankton (enhancement of algal bloom) to sequester carbon from the atmosphere [9]. The mechanism involved a simple photosynthesis processes of which phytoplankton will retained carbon within their cells during photosynthesis for processing food and when they die, remaining carbon embedded within their cells will be confined and sequestered in the deep ocean [9]. Few studies had approached ocean fertilization method and most have suggested that dissolved nutrient, particularly iron, into the ocean has led to some extent of carbon dioxide removal from the atmosphere [9,11,12]. It is suggested that a ton input of iron into the ocean is able to sequester roughly 30,000 to 110,000 tons of CO_2 [9]. Although ocean fertilization helps to reduce atmospheric CO_2 concentration, other studies have also found that by increasing carbon sequestration in the deep ocean, the process can contribute to the increase of ocean acidification of which in return, could result in the disruption of marine biodiversity through coral bleaching and decalcification of shelled molluscs [5,9,12,13]. In addition, McCauley et al. [5] argued that intentional chemical introduction into the ocean may accelerate the extinction of several sensitive marine biodiversity. Another study by Blain et al. [12] further added that effective carbon sequestration through phytoplankton bloom should not be used as a method of geoengineering due the method being highly unsustainable and could posed great environmental risks in the long run.

4.2 CDR Option 2: Afforestation

Afforestation involves planting trees seedling on open land to naturally sequester CO_2 from the atmosphere [9]. The method is deemed as a prime geoengineering technique and a great climate change mitigation strategy as forest can stored huge amount of CO_2 up to 2.2 to 9.5 metric tons per acre per year [9]. Several studies indicated that afforestation is one of the important indicators to project future CO_2 concentration and can be one the most cost-effective strategies for any climate mitigation methods [9,14,15]. These studies also include benefits of afforestation such as erosion control, wildlife habitat reclamation, and can be used for recreational purposes [9,14,15]. Furthermore, in Woziwoda and Kopec [16] study, they observed that afforestation had been fairly effective in conservation of plant species diversity over an abandoned exposed peatlands, thus in essence conserving local biodiversity whilst minimizing CO_2 release into the atmosphere from these peatlands. Although afforestation tends to be a best solution to mitigate climate change, there are drawbacks associated with the method. These drawbacks may include accidental CO_2 released due to drought or forest fires, lands reclamation for crop-based industries, and land reclamation for residential areas for growing human population [9]. Other than that, there are existence of economically driven interests of certain parties on how much will afforestation might cost them their livelihood and source of income [17]. Biodiversity-wise, possible drawbacks may include displacement and extinction of original species due to introduction of newer species through afforestation of which can grow and populate afforested area faster than original species [18].

4.3 SRM Option 1: Enhanced Albedo

Enhanced albedo consists of increasing reflectivity of solar forcing through brightening of Earth's surfaces and cloud whitening using addition of cloud-condensation nuclei (CCN) [9]. This method utilized the concept of solar radiation reflectivity of which by increasing Earth's albedo, more incoming solar radiation will be reflected back to space thus limiting further temperature increase [9]. The Royal Society (2009) reported that in order to radiatively cools Earth of approximately 4 W/m^2, we need to modify current surface albedo so that current total solar radiation reflection increases from ~107 W/m^2 to ~111 W/m^2. For this, a novel idea was proposed to increase surface albedo by using vegetated surfaces through genetically modifying plants' genomes in order to change their surface appearances into brighter or almost reflective in nature [8]. Furthermore, multiple studies conducted had shown that albedo-engineered crops are able to influence regional climate variability by influencing local solar radiation forcing [19,16]. Fig. 2 illustrates global

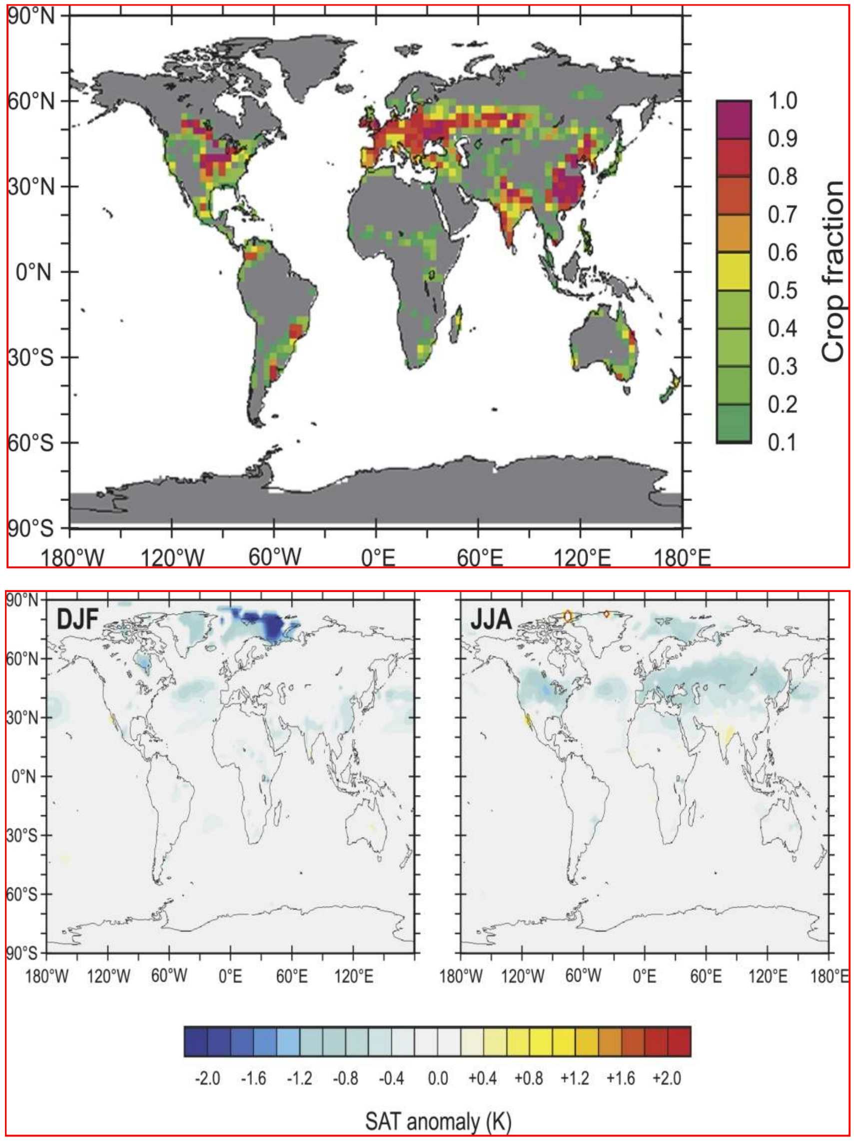

Fig. 2. Global crop distribution and cooling associated with albedo-engineered crops. (Left) Diagram illustrates Earth's surfaces model if covered by albedo-engineered agriculture crops. (Right) Diagram illustrates temperature anomaly taken during December-January-February (DJF) and June-July-August (JJA) if global agriculture surface are covered with albedo-engineered crops. Note that patches above the Northern Hemisphere are corresponding to sea-ice feedback during winter and summer solstices. [16]

agriculture distribution and cooling associated with albedo-engineered crops. Diagrams modeled on the situation whereby all major agriculture crops are albedo-engineered and it is suggested that the potential cooling during summer solstice will be approximately 1 ℃ throughout North America and midlatitude Eurasia [19]. Lenton and Vaughan [20] added that by modifying grassland and cropland albedo, radiative forcing could be reduced up to -0.83 W/m^2. Although model presented is viable, impacts of this method on biodiversity are alarming. Albedo-engineered crops might change the region landscape thus altering ecological behavior surrounding new crops production [19]. In addition, Rigdwell et al. (2009) argued, bio-geoengineering crops can cause extreme drought in part of subtropical countries as well as modify localized soil contents in certain regions around the globe.

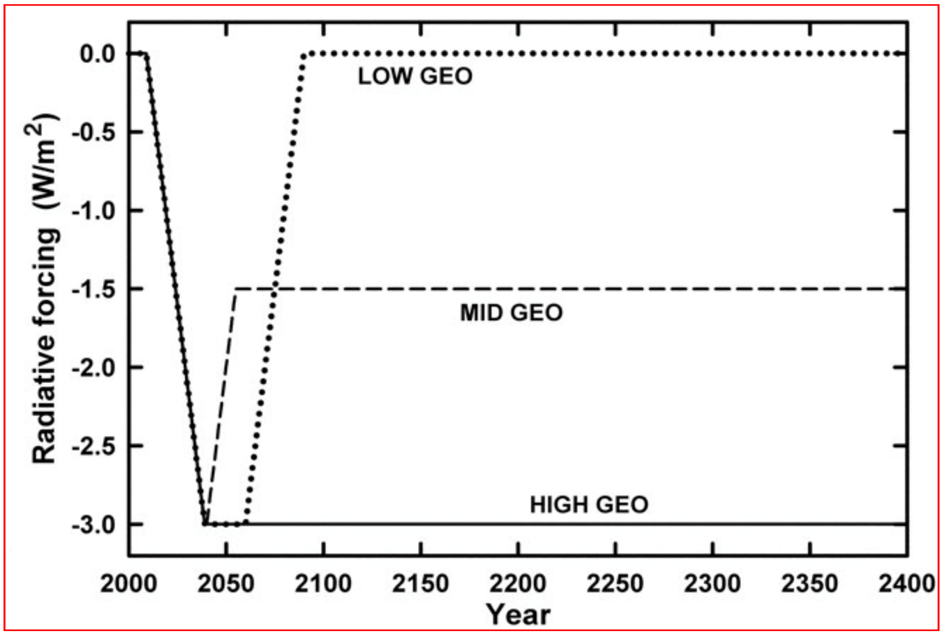

Fig. 3. Reduction of incoming solar radiative forcing based on different geoengineering scenarios. LOW GEO indicates no direct human intervention on modification of climate. HIGH GEO indicates scenario of which released of H_2S and SO_2 through aerosol injection are similar to eruption of Mount Pinatubo for every 2 years. MID GEO indicates mid-level intervention by human whereby aerosol injections are introduced over longer interval period of time. [4]

4.4 SRM Option 2: Aerosol Injection

Aerosol injection is a deliberate attempt to introduce reflective chemical droplets into the atmosphere [9]. Implementation of this method requires aircraft to disperse droplets into the stratospheric layer of the atmosphere where strong mixing of gases occurs [8,9]. These droplets are of the same chemical species produced during volcanic eruptions, particularly of hydrogen sulphide (H_2S) and sulphur dioxide (SO_2) [8,9]. Wigley [4] states that volcanic eruption, drawing example of Mount Pinatubo 1991 incident, provide great scenario of which scientists can study the feasibility of aerosol injection into the stratosphere to modify global climate. Illustrated by Fig. 1, it is observed that during the eruption of Mount Pinatubo, global temperature has dropped for approximately two years before regaining back previous rising momentum. Wigley [4] further added that this eruption not only contribute to a period of global cooling, but is deemed stable as climate has not been seriously affected by eruptive particles. Fig. 3 illustrates the possibility of reduction of incoming solar radiation based on numerical model in which three possibilities of geoengineering manipulations are studied depending on how frequent aerosol injection is introduced into the atmosphere [4]. By using this model, the Royal Society (2009) estimated that aerosol injection might able to reduce incoming solar radiation by 1.84%. In addition, a recent study to evaluate the effectiveness of injecting SO_2 into the stratosphere, found that, only by introducing 5-8 Tg SO_2 yr^{-1} that we may see a probable robust evaluation in mitigating climate for an aerosol injection technique of geoengineering [18,19]. As for biodiversity, geoengineering climate using aerosol injection may provide huge array of problems for life on Earth. Multiple studies indicated that the adverse effects of aerosol injection include intensification of ocean acidification, disruption of regional precipitation, possible enhancement of air pollution, increase frequency of acid rains, and possible contributions to adverse side-effects in human health [4,8,21,22,23]. Other studies focusing on evaluating biodiversity to historical volcanic eruption have also found that species tend to go extinct after major volcanic eruptions and subsequently replaced by other species that able to adapt and survive, thus completely changing the region ecosystem [21,24].

Table 2. Methods explanation of each selected CDR and SRM techniques of geoengineering. Discussion includes small summary and point of pros and cons of each method. Unless specified, points of pros and cons refer to how well methods feasible to geoengineering [1-29]

Methods	Summary	Pro	Cons
Ocean fertilization (CDR)	▪ Done through addition of iron nutrient into the ocean to encourage growth of phytoplankton. As phytoplankton photosynthesize CO_2, carbon will be retain in their cell of which will be sequestered as carbon in Deep Ocean when they die. ▪ Estimated 30,000 to 110000 tons of carbon removed from air.	▪ Reduction of CO_2 in the atmosphere	▪ Ocean Acidification ▪ Marine defaunation ▪ Low effectivity level
Afforestation (CDR)	▪ Done through planting tree seedlings. ▪ Regarded as prime sequestration strategy of which forest able to store carbon for longer time periods. ▪ Able to modify local climate at large scale afforestation.	▪ Reduction of CO_2 in the atmosphere ▪ Affordable	▪ Forest fire, drought will release CO_2 back into atmosphere. ▪ Loss of original diversity. ▪ Cost-effective
Enhanced albedo (SRM)	▪ Done through increasing reflectivity or certain surfaces. ▪ Using reflective paints (white) on building surfaces. ▪ Modification of plant to augment albedo. ▪ Cloud whitening through dispersion of cloud-condensation nuclei (CCN).	▪ Limit temperature increase through enhanced solar radiation reflectivity. ▪ Low safety risks	▪ Cost of implementation ▪ Marginally effective ▪ Displacement of species
Aerosol injection (SRM)	▪ Done through injection of aerosol particularly H_2S and SO_2 into the stratosphere. ▪ Help to either direct solar radiation back to space or to absorb heat.	▪ Limit temperature increase through enhanced solar radiation reflectivity or by absorbing heat. ▪ Very effective	▪ Ocean acidification. ▪ Irregular precipitation ▪ Acid rain ▪ Species extinction

5. CONCLUSION

Geoengineering has been mostly targeted to tackle climate change, however, it is also best to say that geoengineering can be an essential tool to tackle other dependent of climate change such as biodiversity. Each method presented of either CDR or SRM techniques has their own strengths and weaknesses depending on how they are implemented globally and how they affected biodiversity. In term of accessing feasibility of these four methods with biodiversity, most of methods presented are somewhat ignoring the impacts they have on biodiversity itself as they focus solely on the objectives to reduce global warming. Nonetheless, to be neutral, it can be argued that since there are only few researches that had been dedicated on finding biodiversity implications through geoengineering techniques, this may limit the factual as well as theoretical evidences of each method used in CDR and SRM techniques against biodiversity.

Out of all four methods discussed, only afforestation of CDR technique has so far fit with stated hypothesis. It has been argued that, afforestation has not only helps to geoengineer climate through CO_2 sequestration but the method may also help in the conservation of biodiversity, thus making biodiversity resilience towards the future and become more sustainable [9]. Lang et al. [28] stated that afforestation has not only benefiting the wood industries but it is a win-win system of which biodiversity is enriched through carbon sequestration, nutrient retention, and groundwater recharge. In addition, afforestation method is one of the most affordable ways to geoengineered the climate and reclaimed used lands with estimated cost of USD65 to USD200 per acre depending on species planted and regional locations [8,9]. However, it is worth to keep in mind that despite afforestation may help in conserving biodiversity as a whole, some biological species within the afforestation areas can be disturbed and displaced thus altering original ecosystem interaction [16,29]. Ridgwell et al. [27] argued that as long changes can make impacts on climate (and biodiversity), sacrificing few for that change is deemed necessary. So far, safety risks associated with afforestation are generally kept at minimal level [8]. Future suggestion for geoengineering research is to include necessary section on biodiversity against impacts of individual methods proposed in the geoengineering techniques, both CDR and SRM.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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