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The Potential Legal Issues, and Challenges of Utilising Geoengineering in Climate Change Mitigation

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Abstract

Geoengineering is considered a potential scientific technique involving carbon dioxide removal and solar radiation management, aimed at manipulating Earth's climate to mitigate the effects of global climate change. However, despite the potential of geoengineering, there are several legal, environmental, socio-economic, and ethical issues associated with its reliance. Concerning this, the aim is to evaluate geoengineering as an option for mitigating climate change while critiquing legal deficiencies and proposing policy measures for its regulation. Hence, the study adopts a doctrinal method, relying on primary and secondary research materials such as international law, scholarly articles by learned authors, and other relevant sources. A descriptive and analytical style was adopted in analysing the data obtained from the research sources. The findings reveal that the scientific concept of geoengineering is quite promising in mitigating the impacts of climate change through carbon emissions and the management of solar radiation. However, there seems to be a lack of clear legal regulation, leading to a lack of oversight of geoengineering activities, uncertainty about liability for environmental harm, and cross-border issues. Furthermore, developing countries may also face the challenges of adapting to new scientific concepts, given the technical and scientific skills involved, and the inability to fund the geoengineering project. The study agrees that geoengineering has the potential to curtail climate change but concludes that its legal, ethical, and socio-economic challenges should be addressed by the international community through an effective legal framework and the provision of financial aid to developing countries to ensure the responsible application of geoengineering in climate change mitigation.

Keywords: *Geoengineering, Climate Change, Environment.*

INTRODUCTION

This research investigates the potential of geoengineering as a climate change mitigation tool while addressing legal issues regarding its use. This will be from an analytical perspective, considering ethical issues and regulatory gaps to determine possible recommendations. This is in view of the fact that the global environment has, over time, been experiencing severe climate change, due to harmful human activities and industrialisation.[1] Several scholars and scientists have argued that ongoing pollution and degradation of the global environment, leading to severe climate change, could trigger an imminent climate catastrophe.[2] The international community has been proactive in implementing legal frameworks to curtail the impact of harmful human and industrial activities that threaten the environment. Despite these efforts, climate change leading to irregular or prolonged rainfall, drought, biodiversity loss, flooding, excessive heat, hurricanes, and desertification continues. This ha]s prompted the international community to task scholars and scientists to develop potential strategies that could aid in mitigating climate change resulting from carbon emissions and solar radiation.[3]

More researchers have turned their attention to using geoengineering technology to cope with climate change and complement mitigation technologies, which imply limiting greenhouse gas emissions at their origin.[4] Besides limiting emissions, geoengineering involves manipulating Earth systems to regulate solar radiation and remove carbon dioxide from the atmosphere. It is divided into two main categories: Carbon Dioxide Removal (CDR) and Solar Radiation Management (SRM).[5] The latter

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[1] Paul Atagamen Aidonojie, "Environmental Hazard: The Legal Issues Concerning Environmental Justice in Nigeria," *Journal of Human Rights, Culture and Legal System* 3, no. 1 (2023): 18–20, https://doi.org/10.53955/jhcls.v3i1.60; Paul Aidonojie et al., "The Environmental Conservation, Legal and Ethical Issues Concerning Herbal Products in Nigeria," *Journal of Environmental Science and Economics* 1, no. 3 (2022): 27–28, https://doi.org/10.56556/jescae.v1i3.124.

[2] Alec Feinberg, "Annual Solar Geoengineering: Mitigating Yearly Global Warming Increases," *Climate* 12, no. 2 (2024): 26–39, https://doi.org/10.3390/cli12020026.

[3] Anthony C. Jones et al., "Regional Climate Impacts of Stabilizing Global Warming at 1.5 K Using Solar Geoengineering," *Earth's Future* 6, no. 2 (2018): 230–51, https://doi.org/10.1002/2017EF000720.

[4] Bradley A. Gay et al., "Assessing the Impacts of Mitigation and Geoengineering Intervention Scenarios on Earth System Dynamics and Climatological Variability with Multimodal Simulations," *Scientific Reports* 15, no. 1 (2025): 1–25, https://doi.org/10.1038/s41598-025-91195-6.

[5] Kaitlin T. Raimi et al., "Framing of Geoengineering Affects Support for Climate Change Mitigation," *Environmental Communication* 13, no. 3 (2019): 300–319, https://doi.org/10.1080/17524032.2019.1575258.

includes methods such as stratospheric aerosol injection and marine cloud brightening, which involve reflecting part of the energy from the sun to reduce the temperature of our planet. However, CDR technologies involve removing carbon dioxide from the atmosphere through direct air capture, ocean fertilisation, and afforestation-based systems. It is worth noting that they are now used not only to address current emissions but also to cope with past emissions. Although SRM can cool the atmosphere quickly and temporarily, CDR is considered more stable and long-lasting.

The practice of geoengineering is intricately related to international environmental law since large-scale modifications of the Earth's environment by this method may lead to effects beyond one nation, affecting ecosystems, meteorological phenomena, oceans, and human beings.[6] The methods of SRM and CDR pose issues in terms of international environmental law principles such as the doctrine of prevention,[7] the precautionary principle, sustainable development, and intergenerational equity. Current international environmental law instruments, for example, the UNFCCC, CBD, and even customary international environmental law, offer some insights on this matter but lack a complete framework of regulation for geoengineering projects.[8] Thus, there is uncertainty about legal issues related to authorisation, monitoring, compliance, and enforcement. Liability for damage done through crossing borders, responsibility for unforeseen consequences, and control of states and other actors involved in modifying the climate are major concerns in this case.[9] There are also

[6] Paul Atagamen Aidonojie et al., "Potential and Legal Challenges of the Metaverse for Environmental Awareness and Sustainability in Nigeria: A Comparative Analysis with Singapore," *Administrative and Environmental Law Review* 5, no. 1 (2024): 33–58, https://doi.org/10.25041/aelr.v5i1.3230.

[7] Folasade Folake Aare et al., "Legal Frameworks for Single-Use Plastic Management: Environmental Challenges and Solutions," *Kampala International University Law Journal (KIULJ)* 6, no. 1 (2024): 63–85, https://doi.org/10.59568/KIULJ-2024-6-1-04.

[8] Oluwatoyin Oyeronke Ajayi, "Mining in Nigeria and Environmental Protection: Examining the Legal and Institutional Frameworks," *Kampala International University Law Journal (KIULJ)* 5, no. 2 (2023): 238–57, https://doi.org/10.59568/KIULJ-2023-5-2-11.

[9] Esther Oloworaran Uchechukwu, "An Evaluation Of The Legal Framework For Resolving Disputes In The Digital Ecosystem In Nigeria," *Kampala International University Law Journal* 5, no. 2 (2023): 50–64, https://doi.org/10.59568/KIULJ-2023-5-2-03; Nathan Ibrahim, "Examining the Nigerian Hire Purchase Act: Addressing Monetary Limitations and Imbalances in Legal Protection to Enhance Commercial Development," *Nexus International University Journal of Legal Studies* 11, no. 1 (2025): 6–7, https://doi.org/10.58709/niujls.v11i1.2130.

ethical questions regarding the consent of affected people, equity in the distribution of risks, and the geopolitical use of climate technology.

This paper will explore the legal and regulatory aspects of geoengineering in terms of governance gaps, ethical issues, and appropriateness of the legal framework at the international level. Despite extensive academic discussions on the science, technology, and economics of geoengineering, including carbon dioxide removal (CDR), solar radiation management (SRM), polar SRM, stratospheric aerosol injection (SAI), and marine geoengineering approaches, fewer studies have examined the legal regulation of the phenomenon. Zhang et al.[10] provide an account of the varying regulatory efficacy and geography of CDR and SRM, while Smith et al. shed light on polar SRM and its infrastructure requirements. Tilmes et al. investigate SAI models and their effects on the atmosphere, whereas Boettcher et al. stress the ethical governance of marine CDR approaches.[11] However, this paper seeks to bridge legal analysis and discussions of geoengineering to identify regulatory shortcomings and ethical dilemmas associated with such an approach. Despite the increasing acceptance of geoengineering as a strategy for climate change mitigation, there are risks involved in terms of environmental destruction, cost, and liability issues.[12] Therefore, this paper will apply doctrinal methodology in analysing legal and ethical aspects of geoengineering in climate change mitigation.

METHODOLOGY

Because the study tends to focus on the scientific concept of geoengineering and to examine its potential legal challenges, the study relied on the use of a doctrinal research method. In this regard, the study places heavy reliance on primary research materials, including several international treaties, conventions, and protocols.

[10] Zhihua Zhang et al., "Review of Geoengineering Approaches to Mitigating Climate Change," *Journal of Cleaner Production*, Carbon Emissions Reduction: Policies, Technologies, Monitoring, Assessment and Modeling, vol. 103 (2015): 898–907, https://doi.org/10.1016/j.jclepro.2014.09.076.

[11] Jason J. Blackstock and Sean Low, *Geoengineering Our Climate?: Ethics, Politics, and Governance* (Routledge, 2018), 240–49.

[12] Daniel A. Farber and Cinnamon Piñon Carlarne, *Climate Change Law* (Foundation Press, 2018), 260–67.

Furthermore, the study also relied on scholarly articles from journals, internet sources, and other relevant research material.[13] To effectively review and discuss the data obtained from this research material, the study utilises a descriptive and analytical approach in reviewing the research material from the primary and secondary sources.[14] By engaging with and reviewing relevant literature, the research examines legal, governance, and ethical conflicts with geoengineering, following processes that consider both legal and policy implications for future mitigation of climate change.

RESULT AND DISCUSSION

Concept of Geoengineering and its Potential Towards Climate Change Mitigation

Climate change is one of the most formidable threats currently posed to humankind, with extreme weather events, rising temperatures, and environmental degradation threatening ecosystems and human societies.[15] In response to those threats, geoengineering is considered a possible technological intervention that could alter the climate system to mitigate the effects of climate change.[16] Although geoengineering presents opportunities, the major risk is that more opportunities are foregone due to limitations on mitigation and adaptation. Geoengineering, known as climate engineering, is the intentional large-scale intervention in the Earth's natural systems to counteract and curtail climate change.[17] This can be done by sequestering greenhouse gases from the atmosphere or by modifying or managing solar radiation to cool the planet. It is seen as both an alternative and a complement to conventional means of climate mitigation.

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[13] Mark Van Hoecke, *Methodologies of Legal Research: Which Kind of Method for What Kind of Discipline?* (Bloomsbury Publishing, 2011), 290–300.

[14] Dawn Watkins, *Research Methods in Law* (Routledge, 2017), 320–29.

[15] Osikemekha Anthony Anani et al., "Bio-Nano Filtration as an Abatement Technique Used in the Management and Treatment of Impurities in Industrial Wastewater," in *Bio-Nano Filtration in Industrial Effluent Treatment* (CRC Press, 2023), 20–24.

[16] Paul Atagamen Aidonojie, "Environmental Hazard: The Legal Issues Concerning Environmental Justice in Nigeria," *Journal of Human Rights, Culture and Legal System* 3, no. 1 (2023): 17–32, https://doi.org/10.53955/jhcls.v3i1.60.

[17] Paul Atagame Aidonojie et al., "A Facile Review on the Legal Issues and Challenges Concerning the Conservation and Preservation of Biodiversity," *Global Sustainability Research* 2, no. 2 (2023): 34–46, https://doi.org/10.56556/gssr.v2i2.461.

Climate change continues to be one of the most significant global problems, as it has been leading to global warming, weather anomalies, extinction of certain species and destruction of the environment.[18] In an attempt to counter the impacts of global warming, geoengineering has been proposed as a solution to the issue through deliberate modifications of the climate on our planet. Known under the umbrella term climate engineering, geoengineering is an innovation that supplements traditional mitigation strategies by removing greenhouse gases from the atmosphere or reducing the solar radiation absorbed by the Earth.[19] The technologies of Carbon Dioxide Removal (CDR) include afforestation, reforestation, Bioenergy with Carbon Capture and Storage (BECCS), and Direct Air Capture (DAC).[20] These techniques can help reduce atmospheric carbon dioxide levels to prevent global warming. Afforestation and reforestation are natural and economical approaches, whereas BECCS and DAC are innovative methods for carbon removal.

Solar Radiation Management (SRM) is the second type of geoengineering and aims to reduce planetary temperature by reflecting part of the sunlight that enters the Earth back to space.[21] Such approaches include stratospheric aerosol injection (SAI), marine cloud brightening, and space reflectors. While the technologies are capable of quickly lowering planetary temperatures, they also pose challenges related to potential environmental impacts, changes in weather patterns, and regulatory issues. The use of geoengineering technologies is justified by the Anthropocene Governance Theory, which suggests that, since human activity has greatly altered the Earth's system, deliberate interventions might be required to restore climatic stability.[22] The concept

[18] Christopher L. Cummings and Sonny Rosenthal, "Climate Change and Technology: Examining Opinion Formation of Geoengineering," *Environment Systems and Decisions* 38, no. 2 (2018): 208–15, https://doi.org/10.1007/s10669-018-9683-8.

[19] Paul Atagamen Aidonojie et al., "Legal Implications of Nanobiosensors Concerning Environmental Monitoring," in *Nanobiosensors for Environmental Monitoring*, ed. Ravindra Pratap Singh et al. (Springer International Publishing, 2022), 440–41, https://doi.org/10.1007/978-3-031-16106-3_21.

[20] Aobo Liu et al., "Solar Geoengineering and Carbon Removal Significantly Lower Economic Climate Damages," *One Earth* 6, no. 10 (2023): 1375–87, https://doi.org/10.1016/j.oneear.2023.09.004.

[21] Yuanchao Fan et al., "Solar Geoengineering Can Alleviate Climate Change Pressures on Crop Yields," *Nature Food* 2, no. 5 (2021): 373–81, https://doi.org/10.1038/s43016-021-00278-w.

[22] Stephen Gardiner and Catriona McKinnon, "The Justice and Legitimacy of Geoengineering," *Critical Review of International Social and Political Philosophy* 23, no. 5 (2020): 557–63, https://doi.org/10.1080/13698230.2019.1693157; Mary Amoakoh Coleman et al., "Ethical Considerations for Biobanking and Use of Genomics Data in Africa: A Narrative Review," *Bio Medical Centra: Medical Ethics* 24, no. 1 (2023): 109–10, https://doi.org/10.1186/s12910-023-00985-y.

is also based on the risk-risk trade-off theory, according to which the potential danger of geoengineering must be compared to the potential dangers of doing nothing. Some pilot projects include Stratospheric Controlled Perturbation Experiment (SCoPEx) from Harvard University and Orca Direct Air Capture from Iceland. Yet there are many legal and regulatory uncertainties, as there are no clear international agreements governing geoengineering.

Geoengineering has been trialled in different pilot projects and simulations. For example, the SCoPEx project at Harvard University is trying to establish the feasibility of using stratospheric aerosol injections to reflect sunlight and cool the Earth's atmosphere.[23] Similarly, the Orca plant in Iceland is one of the projects that are putting carbon capture technologies on the map, proving that direct air capture can remove CO_2 from the atmosphere. However, overseas governance on geoengineering is still a challenge, as worldwide agreements such as the Paris Agreement do not give a clear legal path for geoengineering techniques.[24]

Potential Dangers and Hazards of Geoengineering Towards Climate Change Mitigation

Even though this technology might help address global warming, it raises many controversial issues[25]. The first one is connected to the moral hazard argument, according to which the use of technological climate interventions can be harmful because people would not make efforts to reduce greenhouse gas emissions. Another issue is that geoengineering technologies can cause unforeseeable environmental and social problems.[26] For instance, Stratospheric Aerosol Injection (SAI) might lead to

[23] Jeff Tollefson, "Harvard Creates Advisory Panel to Oversee Solar Geoengineering Project," *Nature*, 2019, 23–31, https://doi.org/10.1038/d41586-019-02331-y.

[24] Anthony Harding et al., "Impact of Solar Geoengineering on Temperature-Attributable Mortality," *Proceedings of the National Academy of Sciences* 121, no. 52 (2024): 11–21, https://doi.org/10.1073/pnas.2401801121.

[25] Raden Bagus Mochammad Ramadhan Razief Hafid et al., "Countermeasures for Environmental Damage Caused by Drilling Water Sources for The Mineral Water Industry," *Journal of Indonesian Constitutional Law* 1, no. 2 (2024): 140–50, https://doi.org/10.71239/jicl.v1i2.36.

[26] Mou Leong Tan et al., "Assessment of Solar Geoengineering Impact on Precipitation and Temperature Extremes in the Muda River Basin, Malaysia Using CMIP6 SSP and GeoMIP6 G6 Simulations," *Science of The Total Environment* 948 (2024): 2–7, https://doi.org/10.1016/j.scitotenv.2024.174817.

changes in the monsoon system in Africa and South Asia, thus endangering the supply of food and water in these regions. Moreover, there are ethical considerations, as the question of who has the right to conduct this research may become a source of controversy. Besides, the high cost of solar geoengineering (billions of dollars per year) becomes an issue.

Geoengineering technologies offer innovative ways to reduce CO2 concentrations in the atmosphere and limit temperature rise, but at the same time they raise numerous environmental and governance issues. Solar Radiation Management technologies, such as SAI and marine cloud brightening, can have unforeseen climatic consequences since their implementation may affect regional weather patterns.[27] Research shows that the use of solar radiation management on a massive scale will decrease precipitation rates in sensitive regions like the Sahel, thus intensifying food insecurity and water shortages in such areas. This is another illustration of the unpredictability of the consequences of geoengineering technologies. Therefore, it is crucial to conduct rigorous research and implement an effective regulatory framework for the safe application of these innovative technologies.

Another subject under discussion is the ethical and political implications of geoengineering deployment. These are expected to have a significant global impact; such decisions regarding geoengineering interventions might be made under the dominance of some powerful states or private companies and exclude the voices of less developed countries, which are more likely to be affected by the unintended consequences of these interventions. The issue of hazard is also very crucial; reliance on geoengineering could lower global commitments in reducing greenhouse gas emissions because countries and corporations might rather devise short-term technological remedies rather than undertake systemic decarbonization efforts. The prospect of unilateral deployment complicates global governance, as exemplified by disputes over private experiments such as the Stratospheric Controlled Perturbation

[27] Jesse L. Reynolds, "Solar Geoengineering to Reduce Climate Change: A Review of Governance Proposals," *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences* 475, no. 2229 (2019): 12, https://doi.org/10.1098/rspa.2019.0255.

Experiment (SCOPEX), which faced backlash over concerns about transparency and potential risks.[28]

Finally, the long-term consequences of geoengineering are uncertain, potentially leading to irreversible damage to ecosystems. Unlike conventional mitigative systems, which try to tackle the emission source, geoengineering interventions will generate dependencies that are difficult to reverse. For instance, if stratospheric aerosol injection is stopped at once, sudden release of trapped greenhouse gases will create a phenomenon known as "termination shock" with rapid and extreme temperature increases. Such abrupt swings in the climate can have devastating impacts on biodiversity and human societies. There is also the contention that altering the Earth's radiative balance would not affect other important environmental issues, such as ocean acidification, which threatens marine ecosystems regardless of atmospheric CO_2 levels. These uncertainties notwithstanding, the best strategy for addressing climate change is to focus on deploying sustainable, low-risk mitigation measures such as renewable energy expansion, reforestation, and energy efficiency.[29]

Legal Framework on the Use of Geoengineering in Climate Change Mitigation

The global environment seems to be experiencing severe climate change, even though the global community has a legal framework to curtail harmful human and industrial activities by regulating their actions and inactions. However, several of these laws allow nations to share knowledge of their scientific and digital technology discoveries concerning potential solutions towards climate change mitigation., Geoengineering stands out among these scientific or digital technologies. Though the discovery of geoengineering seems to be a potential tool for curtailing or reducing the adverse effects of climate change, whether the procedures, regulations, and context through

[28] John A. Dykema et al., "Stratospheric Controlled Perturbation Experiment: A Small-Scale Experiment to Improve Understanding of the Risks of Solar Geoengineering," *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* 372, no. 2031 (2014): 3–5, https://doi.org/10.1098/rsta.2014.0059.

[29] Rebecca R. Hernandez et al., "Efficient Use of Land to Meet Sustainable Energy Needs," *Nature Climate Change* 5, no. 4 (2015): 355–56, https://doi.org/10.1038/nclimate2556.

which geoengineering can be utilised are provided by law requires deep consideration through the analysis of the existing international environmental laws.

One international environmental law that concerns geoengineering is the United Nations Framework Convention on Climate Change, also known as UNFCCC.[30] The convention was adopted to address the incidence of climate change on Earth. The essence, as stipulated by Article 2 of the convention,[31] focuses on curbing and regulating carbon dioxide and other harmful gas emissions. A review of this provision seems to show that geoengineering, most especially carbon dioxide removal, could aid as a potential means towards climate change stabilisation as contemplated by Article 2. Also, Article 3[32] requires promoting international cooperation to combat climate change. Concerning this, Article 4[33] further requires member states to ensure effective cooperation in technology, science, and technical matters, including the sharing of research findings and knowledge related to climate change mitigation. In this regard, geoengineering could be considered. In this regard, the knowledge as it concerns the procedure, application, and risks involved in utilising geoengineering is required to be disseminated among member states. Article 4 also stipulates that developed nations should endeavour to give financial support to developing nations that may not be able to afford scientific and digital technology to mitigate climate change. Also, Article 4[34] requires developing nations, or nations that have made a discovery, such as in geoengineering, to take the initiative to ensure proper transfer and access to this technology or scientific discovery among member states. This is to avoid monopolising geoengineering and open avenues for joint efforts towards climate change mitigation. These digital technologies or scientific discoveries could be a blessing to mankind or a potential threat to the global environment. Hence, Article 3(3) of the Convention[35] requires nations to embark on projects that are considered sustainable, having less or no adverse effect on the environment. Before

[30] United Nations Framework Convention on Climate Change (1992).
[31] Reynolds, "Solar Geoengineering to Reduce Climate Change: A Review of Governance Proposals," 33.
[32] Reynolds, "Solar Geoengineering to Reduce Climate Change: A Review of Governance Proposals," 36.
[33] Reynolds, "Solar Geoengineering to Reduce Climate Change: A Review of Governance Proposals," 37.
[34] Reynolds, "Solar Geoengineering to Reduce Climate Change: A Review of Governance Proposals," 41.
[35] Reynolds, "Solar Geoengineering to Reduce Climate Change: A Review of Governance Proposals," 42.

geoengineering could be utilised to address climate change, all potential environmental threats must be resolved through an impact assessment. Article 3 of the convention seems to align with the precautionary principle, which requires that adequate measures be taken to curtail the incidence of adverse effects that could arise from such projects as geoengineering.

The Kyoto Protocol and the Paris Agreement seem to be a build-up of the UNFCCC. Both treaties deal with the reduction of carbon dioxide by developed nations and ensure a balance of global temperature as stipulated by their respective provisions, which seem to correspond to the practical use of geoengineering. For example[36], Article 2 of the Kyoto Protocol requires that developed member states, listed in Annex 1 to the protocol,[37] commit to their stipulated carbon emissions levels by adopting measures that enhance carbon sinks, greenhouse gas reservoirs, and efficient energy utilisation. Article 12 of the Kyoto Protocol[38] further requires member states to adopt clean and sustainable mechanisms towards climate change mitigation. This provision seems to contemplate geoengineering as it concerns carbon gas reduction or removal through reforestation, afforestation, and carbon gas sequestration, which aim to capture carbon gas from the atmosphere for reintroduction as oxygen. It must also be noted that the Paris Agreement of 2015,[39] through Article 2, seems to justify the essence of adopting the scientific discovery of geoengineering, and its methods such as solar radiation management. This concerns the fact that Article 2 of the Paris Agreement[40] requires members to ensure that the global temperature is held below 2°C and limit it to 1.5°C, which solar radiation management seeks to achieve.[41] Also, Articles 4 and 10 of the Paris Agreement[42] require member states to ensure rapid reduction of carbon through the best available science and by sharing technological innovation for climate change mitigation. Though geoengineering is not specifically

[36] Kyoto Protocol to the United Nations Framework Convention on Climate Change (1997).
[37] Kyoto Protocol to the United Nations Framework Convention on Climate Change Art. 1.
[38] Kyoto Protocol to the United Nations Framework Convention on Climate Change Art. 12.
[39] United Nations Framework Convention on Climate Change.
[40] United Nations Framework Convention on Climate Change Art. 2.
[41] United Nations Framework Convention on Climate Change Art. 2.
[42] United Nations Framework Convention on Climate Change Art. 4 & Art. 10.

mentioned in the Paris Agreement, it is a potential scientific innovation that could fall within the scope of Article 4.[43]

Both the UNFCCC, the Paris Agreement, and the Kyoto Protocol recognise geoengineering as a complementary scientific tool that could aid in climate change mitigation. The Kyoto Protocol and the UNFCCC influence the principle of common but differentiated responsibilities among states, which is based on the idea that developed states must assist and share knowledge on climate change mitigation through carbon emissions reduction. Hence, it requires that geoengineering developed by developed states be used to aid developing nations.

Although geoengineering is recognised by international environmental laws as a potential tool for climate change mitigation, it could also pose threats to the global environment. This view has been supported by Adelman, who stated that geoengineering poses serious threats to the global ecosystem through SRM and CDR, leading to unintended and uncontrollable outcomes that may violate human rights and lack governance. [44] Likewise, Propels and Steenkamp describe how geoengineering is increasingly viewed as one response to the climate crisis; geoengineering policies and programs may also have negative transboundary environmental impacts, which will elicit complex questions of international liability.[45] Together, these sources emphasise that while geoengineering might seem like the ultimate solution to climate change, it also might pose risks to ecological integrity, ecosystems, and vulnerable communities in the absence of governance.

Several international environmental laws address these issues, but none specifically mention geoengineering. For example, the Espoo Convention requires member states to undertake an assessment of the negative impact that any project is likely to have on the environment.[46] Article 2, of the Espoo Convention stipulates that the objective of

[43] United Nations Framework Convention on Climate Change Art. 4.

[44] Sam Adelman, "Geoengineering: Rights, Risks and Ethics," *Journal of Human Rights and the Environment* 8, no. 1 (2017): 119–38, https://doi.org/10.4337/jhre.2017.01.06.

[45] Alexander Proelss and Robert C. Steenkamp, "Geoengineering: Methods, Associated Risks and International Liability," in *Corporate Liability for Transboundary Environmental Harm*, ed. Peter Gailhofer et al. (Springer International Publishing, 2023), 421–22, https://doi.org/10.1007/978-3-031-13264-3_9.

[46] Convention on Environmental Impact Assessment in a Transboundary Context (1991).

the convention is curtailing potential damage through an environmental assessment of the impact.[47] Article 2(3) of the Convention requires member states to notify other member states that are likely to be affected by their intended project or activity. In addition, Article 3(1) of the Espoo Convention identifies activities in Annex 1[48] to the Convention that are likely to cause environmental hazards; hence, it places a strict obligation on member states to notify parties likely to be affected. Member states utilising geoengineering are required to observe and commit to the Espoo Convention. Article 4 stipulates that where a project, such as geoengineering, is likely to cause environmental harm, the executing member state must ensure that it has prepared a relevant environmental impact assessment document. Articles 5 and 6 of the Espoo Convention[49] require due consultation with neighbouring states to ensure effective public participation in resolving potential consequences that could arise during the intended project. One major potential issue with the Espoo Convention is that Annex 1 lists activities for which an environmental impact assessment must be conducted; however, geoengineering is not on the list.

The Montreal Protocol[50] on Substances that Deplete the Ozone Layer, adopted in 1987, is also considered relevant to the use of geoengineering as a climate change mitigation tool. Article 2 of the Montreal Protocol mandates controlling and limiting substances that could cause environmental harm.[51] It also requires member states to phase out substances that are likely to cause severe environmental impact. In circumstances where geoengineering uses SAI in the atmosphere, the dangerous chemicals involved could violate this provision. This process could result in weather manipulation and alteration that could be adverse to the global environment. However, Article 3 imposes restrictions and controls on substances related to import and export. Article further stipulates that control measures on substances should be constantly reviewed by environmental, scientific, economic, and technical information. This provision aims

[47] Cosmos Nike Nwedu, "Exploring the Legal and Policy Impact of the Russia-Ukraine War on Energy Security," *Kampala International University Law Journal* 6, no. 1 (2024): 28–30, https://doi.org/10.59568/KIULJ-2024-6-1-02.

[48] Nike Nwedu, "Exploring the Legal and Policy Impact of the Russia-Ukraine War on Energy Security," 33–35.

[49] Convention on Environmental Impact Assessment in a Transboundary Context Art. 5 & Art. 6.

[50] Montreal Protocol on Substances That Deplete the Ozone Layer (1987).

[51] Montreal Protocol on Substances That Deplete the Ozone Layer Art. 2.

to detect substances used in geoengineering that could harm the environment. Although Annex A and B of the Montreal Protocol [52] have not mentioned geoengineering, many substances that are used in geoengineering that fall within the provisions of Annex A and B could be subjected to the restrictions of the Montreal Protocol. Article 8 requires strict compliance and requires a mechanism to be put in place to ensure member states comply with the Protocol.

While there are several international environmental laws that protect the global environment, geoengineering remains largely unregulated because international law does not specifically address its use and application. Fragmented laws are close to addressing issues in the use of geoengineering, which could result in gridlock and challenges in implementation. The international community must develop a specific, uniform law to govern the use and application of geoengineering.

Legal Issues and Challenges of the Use of Geoengineering in Climate Change Mitigation

The scientific and technological discovery of geoengineering is considered a potential tool for mitigating climate change. Despite its relevance, several challenges could mitigate the effective reliance of geoengineering if they are not adequately addressed. [53] For example, the legal framework on geoengineering is constructed primarily around international agreements on the environment, such as the Kyoto Protocol, UNFCCC, and the Paris Agreement.[54] These laws place a strong emphasis on carbon emissions reductions, technological cooperation among member states, and sustainable climate strategies, which are indirectly related to several geoengineering techniques, such as carbon dioxide removal and solar radiation management. This is concerning because Article 2 of the UNFCCC prescribes the regulation of the emission

[52] Montreal Protocol on Substances That Deplete the Ozone Layer.

[53] Kingsley Eghonghon Ukhurebor and Paul Atagamen Aidonojie, "The Influence of Climate Change on Food Innovation Technology: Review on Topical Developments and Legal Framework," *Agriculture and Food Security* 10, no. 1 (2021): 50–53, https://doi.org/10.1186/s40066-021-00327-4.

[54] Kingsley Eghonghon Ukhurebor et al., "Environmental Influence of Gas Flaring: Perspective from the Niger Delta Region of Nigeria," *Geofluids* 24 (2024): 2–5, https://doi.org/10.1155/2024/1321022.

of harmful gases, while Article 4[55] requires international cooperation in scientific research, discoveries, and technology transfer. Likewise, the attribution of carbon sinks in the Kyoto Protocol and the Paris Agreement to maintain global temperature from sporadic rising above 2°C are all principles that relate and correspond with geoengineering. However, it suffices to state that no express regulations in these international laws explicitly provide for or govern geoengineering, leading to uncertainty and ambiguity regarding geoengineering governance. Several provisions of the international environmental laws recognise the need for technological advancement, yet several provisions of these laws seem to hinder technological application by advocating for sustainable technological and scientific discoveries.

For example, Article 4(1)(c) of the UNFCCC[56] commits Parties to encouraging and cooperating in the development and transfer of environmentally sound technologies. Similarly, Article 2(1) of the Kyoto Protocol[57] requires member states to implement laws that promote sustainable, environmentally friendly technological innovation. Article 10(1) of the Paris Agreement is similar in this regard; it emphasises the need for technology development and transfer for both mitigation and adaptation efforts to address and curtail climate change. However, in each of these instruments, there is a commitment to achieve sustainability and equity, which could hinder the rapid uptake of controversial approaches to climate mitigation (e.g., geoengineering). Additionally, Article 2 of the Espoo Convention [58] explicitly requires that environmental impact assessments be carried out for activities likely to cause significant transboundary harm, meaning new technologies will need rigorous assessment before being approved for use. These provisions are aimed at protecting sustainability, but they may slow the deployment of potential technologies to counter climate change. Any attempt to address this tension will need to clarify regulatory pathways that balance precautionary safeguards and flexible legal frameworks for responsible innovation in climate mitigation technologies. Environmental impact

[55] United Nations Framework Convention on Climate Change Art. 4.
[56] United Nations Framework Convention on Climate Change Art. 4 (1)(c).
[57] Kyoto Protocol to the United Nations Framework Convention on Climate Change Art. 2(1).
[58] Convention on Environmental Impact Assessment in a Transboundary Context Art. 2.

assessments require that, even if there may be some merit to applying a technology, it may not be implemented if it could lead to adverse environmental impacts. This places a limitation on relying on geoengineering as a method of climate change intervention.[59]

Notwithstanding the potential of geoengineering, there are legal impediments: the current fragmented international regulations are not ay meant to govern its deployment, use, and adverse effects. The few international instruments that mention geoengineering include the Espoo Convention,[60] which outlines environmental risk assessment, and the Montreal Protocol, [61] which deals with the regulation of substances harmful to the ozone layer. However, none of these laws include geoengineering expressly in their mandates. The Espoo Convention creates inherent legal uncertainty. Similarly, should geoengineering methods use substances banned under the Montreal Protocol, this law ought to address them; nonetheless, no provisions concerning geoengineering exist. Because of the lack of adequate legal arrangements regarding the matter, the global application of geoengineering seems largely unresolved. This gap in the law warrants an urgent need for a comprehensive, uniform international legal framework that outlines the limits within which geoengineering can be used, the associated risks, and governance modalities to ensure safety and fairness in its application in the context of climate change mitigation.

Furthermore, it is relevant to note that the viability of geoengineering as a climate change mitigation strategy is challenged by ethical, environmental, and socio-economic problems that make it unsuitable as a long-term solution. The ethical issues arise from governance and decision-making processes that raise questions of equity and justice, as in situations involving geoengineering. Developing nations may face unintended consequences without any say in the implementation of geoengineering projects. Benefited countries, multinational corporations, and nonstate actors may unilaterally deploy geoengineering technologies, such as SAI or marine cloud brightening, that

[59] Proelss and Steenkamp, "Geoengineering: Methods, Associated Risks and International Liability," 426–29.
[60] Convention on Environmental Impact Assessment in a Transboundary Context.
[61] Montreal Protocol on Substances That Deplete the Ozone Layer.

could disrupt global weather patterns, disadvantaging those at risk of food and water insecurity. In addition, there remains the moral hazard issue, in which geoengineering reliance could produce leniency towards global undertakings for emissions reduction if governments and corporations continue to pursue geoengineering technologies as a quick fix, avoiding genuine systemic decarbonization.[62]

From an environmental and socio-economic perspective, geoengineering interventions may trigger unintended, disruptive consequences that outweigh the benefits. For instance, large-scale SRM may also change precipitation patterns and induce droughts or floods in various regions, especially the Global South, whose agricultural economies are extremely climate-dependent. Some of these interventions include carbon dioxide removal methods like direct air capture and bioenergy with carbon capture and storage. Also, international equity considerations must be taken into account in cost-sharing estimates for geoengineering projects, which might range between $10 billion and $100 billion per year, as concerns about the monopolisation of climate technology by wealthy nations and corporations arise. In addition to this, long-term effects of geoengineering continue to remain uncertain; for example, abrupt termination of large-scale interventions such as SAI could induce "termination shock", marked by rapid ramp-up of temperature that could have devastating impacts on ecosystems and human societies.[63]

In geoengineering, the additional hurdles are economic feasibility and long-term sustainability. Although developed and endorsed as viable carbon dioxide removal (CDR) alternatives, direct air capture (DAC) and bioenergy with carbon capture and storage (BECCS) both require substantial capital and energy investments. According to the Intergovernmental Panel on Climate Change (IPCC) report, DAC costs fall between $100-$600 per ton of sequestered CO_2, thereby rendering large-scale deployment extremely uneconomic. Similarly, BECCS competes with land use for food production, raising food security concerns. Monetary estimates for large-scale

[62] Katelyn Tsipiras and Will J. Grant, "What Do We Mean When We Talk About the Moral Hazard of Geoengineering?," *Environmental Law Review* 24, no. 1 (2022): 28–29, https://doi.org/10.1177/14614529211069839.

[63] Juan B. Moreno-Cruz and Sjak Smulders, "Revisiting the Economics of Climate Change: The Role of Geoengineering," *Research in Economics* 71, no. 2 (2017): 213–14, https://doi.org/10.1016/j.rie.2016.12.001.

solar geoengineering projects range from $10 billion to $100 billion per year, leading to questions about who is going to pay for it all and how these costs will be equitably allocated. Additionally, the concentration of technology would lead to monopolisation by a few powerful entities and, thus, further inequities in climate change adaptation and mitigation policies.

CONCLUSION

Geoengineering can provide a solution towards environmental protection via carbon dioxide removal and solar radiation management. Still, there are several factors limiting the implementation of geoengineering, including uncertainty of law, ecological and socio-economic limitations. One of the limitations of geoengineering is the lack of an international legal regime regulating the activities of geoengineering. It means that there are no international laws concerning the liability of states and other parties for possible environmental damage and cross-border effects caused by geoengineering projects. Another important factor limiting geoengineering is the socio-economic constraints of developing states, which lack sufficient finance, technology, and infrastructure to implement such a climate intervention technique. Geoengineering might look like a good solution to the problem of climate change, but the risks and uncertainties associated with it make people concerned about environmental stability and global fairness. The lack of appropriate regulation of geoengineering might lead to an increase in global inequality and the creation of environmental damage. Hence, it becomes evident that an international legal framework is required to ensure effective monitoring and cooperation in relation to the implementation of geoengineering.

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