Edumania-An International Multidisciplinary Journal

@2025 International Council for Education Research and Training 2025, Vol. 03, Issue 03,317-331
ISSN: 2960-0006 DOI: https: https://doi.org/10.59231/edumania/9154

Climate Engineering: Ethical and Environmental Implications

Simran

Professor, Department of Commerce, NIILM University, Kaithal

Abstract

Climate engineering, also known as geoengineering, refers to the deliberate large-scale intervention in Earth's climate system with the aim of mitigating the adverse effects of climate change. As global temperatures rise and conventional mitigation strategies lag behind, interest in these technologies is growing. Climate engineering is broadly classified into two categories: Carbon Dioxide Removal (CDR) and Solar Radiation Management (SRM), each with distinct methodologies, objectives, and risk profiles. While proponents argue that these approaches may offer a critical backup plan in case of climate emergency, critics warn against their uncertain long-term impacts and ethical implications. This paper explores both the environmental and ethical dimensions of climate engineering. It analyzes key techniques under CDR and SRM, potential environmental disruptions, governance gaps, and moral challenges, including issues of consent, intergenerational justice, and equity. Real-world case studies such as the SPICE project in the UK, ocean fertilization by the Haida Nation in Canada, and Iceland's CarbFix initiative are examined to highlight the practical, legal, and societal dilemmas posed by geoengineering. Through an interdisciplinary lens, this study argues that any advancement in climate engineering must be guided by transparent, inclusive governance frameworks that prioritize precaution, sustainability, and justice.

Keywords: Climate Engineering, Geoengineering, Environmental Ethics, Climate Governance, Moral Hazard, Intergenerational Justice

Introduction

The accelerating pace of climate change, driven largely by anthropogenic greenhouse gas emissions, has led to profound global consequences—ranging from rising sea levels and extreme weather events to biodiversity loss and food insecurity. Despite international agreements such as the Paris Agreement and growing investments in renewable energy and carbon reduction strategies,

@2025 International Council for Education Research and Training 2025, Vol. 03, Issue 03,317-331
ISSN: 2960-0006 DOI: https: https://doi.org/10.59231/edumania/9154
current mitigation efforts appear insufficient to prevent catastrophic climate scenarios. In this context, climate engineering—also known as geoengineering—has emerged as a controversial yet increasingly discussed option in climate policy and scientific circles.

Climate engineering refers to the intentional, large-scale manipulation of Earth's climate systems to counteract the effects of global warming. It is typically divided into two major categories: Carbon Dioxide Removal (CDR), which aims to extract excess CO_2 from the atmosphere, and Solar Radiation Management (SRM), which seeks to reflect a portion of incoming solar radiation to cool the planet. Techniques under these categories range from nature-based solutions such as afforestation and ocean fertilization, to more radical interventions like stratospheric aerosol injection and space-based reflectors.

While some argue that geoengineering might offer a much-needed technological buffer to buy time for decarbonization, others caution that these interventions could create unintended environmental disruptions, exacerbate global inequalities, and undermine political will to pursue sustainable climate policies—a concern often referred to as the "moral hazard." Moreover, the absence of clear international regulatory frameworks raises critical questions about governance, accountability, and justice, especially for vulnerable nations and future generations who may bear the brunt of unforeseen consequences.

This paper aims to explore the scientific foundations, practical applications, and most importantly, the ethical and environmental implications of climate engineering. Through detailed case studies and a multidisciplinary analysis, it examines the potential risks, societal dilemmas, and policy challenges associated with deploying such technologies. The goal is not only to assess their feasibility but also to emphasize the importance of precautionary principles, inclusive global dialogue, and equitable climate action in addressing this complex and high-stakes issue.

1. **Types of Climate Engineering**

Types of Climate Engineering (with Explanation and Case Studies)

Climate engineering strategies are generally grouped into two broad categories: Carbon Dioxide Removal (CDR) and Solar Radiation Management (SRM). Each category encompasses a range of technologies with differing scales, mechanisms, benefits, and risks. While CDR addresses the root

@2025 International Council for Education Research and Training 2025, Vol. 03, Issue 03,317-331
ISSN: 2960-0006 DOI: https: https://doi.org/10.59231/edumania/9154

cause of climate change—excess CO_2 in the atmosphere—SRM focuses on altering Earth's energy balance to cool the planet more rapidly.

1.1. Carbon Dioxide Removal (CDR)

CDR refers to technologies or practices that directly extract CO_2 from the atmosphere and either store it underground or use it in a way that keeps it from re-entering the atmosphere

a. Afforestation and Reforestation

Explanation: Planting new forests (afforestation) or restoring degraded ones (reforestation) captures CO_2 through natural photosynthesis.

Pros: Cost-effective and enhances biodiversity.

Cons: Requires vast land areas, potential for conflict with food security and land rights.

Case Study: China's Green Great Wall Project aims to plant 88 million acres of forest to combat desertification and sequester carbon. While successful in tree planting, critics have raised concerns about monoculture forests and water resource strain.

b. Direct Air Capture and Storage (DACS)

Explanation: Machines capture atmospheric CO_2 using chemical solvents and compress it for underground storage or industrial use.

Pros: Can be deployed anywhere, measurable CO_2 removal.

Cons: Expensive, energy-intensive, and currently small-scale.

Case Study: Climeworks (Switzerland and Iceland): This company operates one of the world's first commercial DACS plants, where captured CO_2 is injected into basaltic rock in Iceland via the **CarbFix** process. While promising, scalability and cost remain concerns.

c. Bioenergy with Carbon Capture and Storage (BECCS)

Explanation: Biomass is used to generate energy, and the resulting CO_2 emissions are captured and stored underground.

Pros: Dual benefit of energy generation and carbon removal.

Cons: Competes with agriculture, high water and land use.

Case Study: Drax Power Station (UK) is piloting BECCS technology, capturing CO_2 emissions from biomass-fired power plants. Critics question the sustainability of biomass sourcing.

d. Ocean Fertilization

@2025 International Council for Education Research and Training 2025, Vol. 03, Issue 03,317-331
ISSN: 2960-0006 DOI: https: https://doi.org/10.59231/edumania/9154

Explanation: Addition of iron or other nutrients to ocean water to stimulate phytoplankton blooms, which absorb CO_2.

Pros: Potential for large-scale carbon uptake.

Cons: Uncertain ecological side effects, such as oxygen depletion or harm to marine ecosystems.

Case Study: In 2012, the **Haida Salmon Restoration Corporation** (Canada) dumped 100 tons of iron sulfate into the Pacific Ocean to stimulate plankton. Although it resulted in a large bloom, it sparked global criticism for bypassing scientific and regulatory protocols, violating the **London Convention** on ocean dumping.

1.2. Solar Radiation Management (SRM)

SRM techniques aim to reflect a portion of the sun's radiation back into space to reduce global temperatures. Unlike CDR, SRM does not reduce greenhouse gases and must be maintained continuously.

a. Stratospheric Aerosol Injection (SAI)

Explanation: Injection of reflective particles like sulfur dioxide into the stratosphere to mimic the cooling effect of volcanic eruptions.

Pros: Fast-acting and potentially inexpensive.

Cons: Risk of ozone depletion, regional weather disruption, does not address ocean acidification.

Case Study: The **SPICE Project (UK)** explored the feasibility of SAI by proposing a balloon and hose delivery system. It was canceled due to public and ethical concerns, particularly about potential patent ownership and lack of stakeholder engagement.

b. Marine Cloud Brightening

Explanation: Spraying seawater droplets into marine clouds to increase their reflectivity and longevity.

Pros: Potentially reversible and regionally deployable.

Cons: May alter regional rainfall patterns, ecological uncertainties.

Case Study: The Marine Cloud Brightening Project in the U.S. has tested spray systems on small scales but has yet to move beyond preliminary modeling and technical development due to environmental concerns.

c. Space-based Reflectors

@2025 International Council for Education Research and Training 2025, Vol. 03, Issue 03,317-331
ISSN: 2960-0006 DOI: https: https://doi.org/10.59231/edumania/9154

Explanation: Deploying mirrors or reflectors in space to reduce the amount of solar radiation reaching Earth.

Pros: Theoretically effective on a global scale.

Cons: Extremely costly, high technological barriers, long implementation timeline.

Case Study: While largely hypothetical, NASA and private agencies have modeled **space mirror arrays**. No practical deployment has been attempted due to cost and risk.

Type	Method	Goal	Case Study	Major Concern
CDR	Afforestation	CO_2 capture via trees	China's Green Great Wall	Land and water use
CDR	Direct Air Capture (DAC)	CO_2 removal through machines	Clime works / CarbFix (Iceland)	High cost and energy demand
CDR	Ocean Fertilization	Promote phytoplankton growth	Haida Nation (Canada)	Ecological risk, legal violations
CDR	BECCS	Carbon-negative energy production	Drax Power Station (UK)	Sustainability of biomass
SRM	Stratospheric Aerosols	Reflect sunlight	SPICE Project (UK)	Ozone depletion, ethics
SRM	Marine Cloud Brightening	Enhance cloud reflectivity	MCB Project (USA)	Regional climate shifts
SRM	Space-based Reflectors	Block solar radiation from space	Theoretical NASA models	Cost, feasibility

2. Ethical Implications

The ethical concerns surrounding climate engineering are profound, complex, and far-reaching. Unlike traditional climate solutions, geoengineering technologies intervene in Earth's systems on a planetary scale, raising questions that go beyond scientific feasibility or technical risk. Ethical evaluation must consider justice, consent, responsibility, governance, and the moral foundations of human interactions with nature. This section addresses the most pressing ethical dimensions of climate engineering.

2.1 Informed Consent and Global Justice Geoengineering inherently affects the entire planet, yet decision-making power may lie in the hands of a few technologically advanced or economically

@2025 International Council for Education Research and Training 2025, Vol. 03, Issue 03,317-331
ISSN: 2960-0006 DOI: https: https://doi.org/10.59231/edumania/9154

powerful countries. This asymmetry creates serious concerns about informed consent, especially from developing nations and vulnerable communities who may suffer unintended consequences.

For example, injecting aerosols into the stratosphere may cool the planet globally, but it could disrupt regional rainfall patterns, especially in the Global South. This could threaten food security in areas dependent on monsoons or rain-fed agriculture.

There is currently no legal mechanism to ensure that affected populations have a voice in such decisions. The principle of climate justice demands inclusive and equitable governance where all nations, especially those most at risk, have the right to participate in deliberations.

2.2 Moral Hazard One of the most cited ethical objections to climate engineering is the moral hazard it creates—where the existence or promise of a technological fix reduces the incentive to pursue conventional mitigation strategies like reducing greenhouse gas emissions.

This could delay critical climate action, giving political and corporate actors a justification to continue harmful practices under the false belief that climate engineering can "solve" the crisis.

It also risks reinforcing status quo power structures, where the most polluting nations can maintain their economic dominance without making necessary sacrifices, while shifting risk to others.

Ethical counterpoint: Some argue that inaction in the face of worsening climate impacts is also immoral. If responsibly managed, climate engineering could serve as a temporary emergency measure to prevent catastrophic tipping points.

2.3 Intergenerational Responsibility Geoengineering could lock humanity into long-term dependencies. For instance, once a Solar Radiation Management (SRM) technique like stratospheric aerosol injection is deployed, suddenly stopping it could result in rapid climate rebound or "termination shock," with devastating environmental consequences. Future generations may be forced to continue or escalate these interventions to maintain stability—without having had a say in the initial decision. This raises ethical questions about intergenerational justice: Do we have the right to make irreversible changes to the planet that will constrain the freedoms and well-being of future generations?

2.4 Uncertainty and the Precautionary Principle

Many geoengineering techniques are still in the research or modeling stage, and their long-term ecological and atmospheric effects remain uncertain. According to the precautionary principle, action should not be taken when the risks are poorly understood or potentially catastrophic.

@2025 International Council for Education Research and Training 2025, Vol. 03, Issue 03,317-331
ISSN: 2960-0006 DOI: https: https://doi.org/10.59231/edumania/9154

For example, ocean fertilization may initially boost carbon capture via plankton blooms, but it could also trigger hypoxia, harmful algal blooms, or acidification, threatening entire marine ecosystems.

Ethically, this invokes the duty to do no harm, especially when scientific uncertainty intersects with high-stakes global outcomes.

2.5 Governance and Accountability

Unlike emissions regulations or carbon markets, climate engineering lacks robust governance structures at the global level.

- Who decides if and when a technique is deployed?
- Who monitors and holds actors accountable for unintended consequences?
- What happens if a nation or corporation **unilaterally deploys** a geoengineering solution?
- Without clear international oversight, geoengineering could become a tool of geopolitical power or economic manipulation. Ethical governance must be transparent, participatory, and enforceable, guided by universal values rather than narrow national interests.

2.6 Human Relationship with Nature

Some critics argue that geoengineering represents a technological arrogance or "hubris"—the belief that humanity can control and engineer complex natural systems without fully understanding them.

This worldview reinforces a mechanistic and utilitarian relationship with nature, treating ecosystems as manipulable tools rather than as interconnected, living systems.

Ethical environmental philosophy, especially from deep ecology and Indigenous perspectives, emphasizes the need for humility, respect, and coexistence with natural processes—not domination.

Ethical Concern	**Key Issue**	**Implication**
Informed Consent	Lack of global participation	Marginalization of vulnerable nations
Moral Hazard	Reduced pressure to cut emissions	Delay in systemic climate action
Intergenerational Justice	Long-term consequences without future input	Ethical burden passed to future generations

@2025 International Council for Education Research and Training 2025, Vol. 03, Issue 03,317-331
ISSN: 2960-0006 DOI: https: https://doi.org/10.59231/edumania/9154

Precautionary Principle	Uncertainty of effects	Risk of irreversible ecological damage
Governance and Accountability	No global oversight or regulatory body	Possibility of unilateral action or misuse
Relationship with Nature	Technological manipulation of Earth's systems	Erosion of ecological ethics and respect for nature

3. Environmental Risks

While climate engineering technologies are designed to mitigate the impacts of global warming, their large-scale and often experimental nature poses significant environmental risks. These risks are complex, interconnected, and in many cases, poorly understood due to limited field testing. Unlike traditional mitigation strategies, geoengineering introduces new environmental uncertainties rather than solving the root causes of climate change. This section explores the major ecological concerns associated with both Carbon Dioxide Removal (CDR) and Solar Radiation Management (SRM) techniques.

3.1 Stratospheric Aerosol Injection (SAI) and Ozone Depletion

SAI involves injecting reflective particles, such as sulfur dioxide, into the stratosphere to reduce incoming solar radiation. Although this method could quickly lower global temperatures, it may result in unintended atmospheric changes.

Ozone Layer Threat: Sulfate aerosols can trigger chemical reactions that deplete ozone, particularly in polar regions. The Montreal Protocol successfully reduced ozone-depleting substances, and there is concern that SAI could reverse some of these gains.

Acid Rain: Sulfur aerosols may eventually return to Earth's surface as acid precipitation, harming freshwater ecosystems, soil quality, and forest health.

Weather Disruption: SAI could alter monsoon patterns or jet streams, leading to regional changes in precipitation, droughts in some areas, and flooding in others.

Termination Shock: If SAI is abruptly halted after prolonged use, the atmosphere could experience rapid warming, potentially faster than ecosystems or societies can adapt—a phenomenon known as termination shock.

3.2 Ocean Fertilization and Marine Ecosystems

@2025 International Council for Education Research and Training 2025, Vol. 03, Issue 03,317-331
ISSN: 2960-0006 DOI: https: https://doi.org/10.59231/edumania/9154

Ocean fertilization involves adding nutrients (like iron) to stimulate phytoplankton blooms, which absorb CO_2 during photosynthesis. However, this method carries considerable ecological risks:

Hypoxia and Dead Zones: When phytoplankton die and decompose, the process consumes oxygen, potentially creating oxygen-depleted (hypoxic) zones, devastating marine life.

Food Chain Imbalance: Artificially enhancing one species of plankton may suppress others, disrupt the marine food web and alter biodiversity.

Toxic Algal Blooms: Fertilization may unintentionally encourage harmful algal blooms, some of which produce toxins dangerous to fish, marine mammals, and humans.

Case Example: The **Haida Gwaii experiment** (Canada, 2012) was widely condemned for proceeding without proper regulation, highlighting the potential for **rogue experimentation** with high ecological stakes.

3.3 Direct Air Capture and Storage (DACS) and Resource Demands

Although DACS is seen as a controlled and scalable solution, its environmental footprint must be critically examined:

Energy Intensity: Most DACS systems require large amounts of clean energy to operate. If powered by fossil fuels, the carbon reduction benefit may be negated.

Land and Water Use: Large-scale deployment could compete with agriculture or biodiversity conservation for land and water resources, especially in water-scarce regions.

Storage Risks: Captured CO_2 must be stored safely underground. There's a risk of CO_2 leakage from geological storage sites, which could undermine long-term climate goals and contaminate groundwater.

3.4 Bioenergy with Carbon Capture and Storage (BECCS) and Ecological Trade-offs

BECCS involves growing biomass for energy and capturing the emitted CO_2. It poses a unique set of environmental trade-offs:

Deforestation and Habitat Loss: Large-scale biomass production may lead to **land conversion** from forests or natural grasslands, reducing biodiversity and carbon sinks.

Food vs. Fuel Dilemma: Growing energy crops could increase competition for arable land, leading to **food insecurity**, particularly in low-income countries.

Monoculture Risks: Large-scale bioenergy plantations may promote monoculture, which reduces ecosystem resilience and soil health.

@2025 International Council for Education Research and Training 2025, Vol. 03, Issue 03,317-331
ISSN: 2960-0006 DOI: https: https://doi.org/10.59231/edumania/9154

3.5 Marine Cloud Brightening and Coastal Effects

Marine Cloud Brightening (MCB) seeks to increase the reflectivity of marine clouds by spraying seawater droplets into the atmosphere. While this is considered one of the more reversible SRM methods, it is not without risks:

Regional Climate Impacts: Changing cloud albedo may alter **regional wind and precipitation patterns**, potentially disrupting marine and coastal climates.

Atmospheric Chemistry: The added aerosols may interact with existing pollutants, potentially affecting **air quality** and cloud chemistry.

Ecosystem Feedback Loops: The cooling effect may affect **ocean currents** and **upwelling patterns**, disrupting nutrient flow and marine productivity.

3.6 Risk of Irreversibility and Systemic Dependence

Many geoengineering techniques, especially SRM, introduce the danger of **technological lock-in**: Once deployed, SRM may need to be maintained for **decades or centuries**, creating dependence with no clear exit strategy.

If disrupted due to political instability, war, or funding issues, the world could experience **abrupt warming**, harming ecosystems unprepared for rapid temperature shifts.

Technology	**Environmental Risks**	**Example**
Stratospheric Aerosol Injection (SAI)	Ozone depletion, acid rain, monsoon disruption, termination shock	SPICE Project (UK, proposed)
Ocean Fertilization	Hypoxia, toxic algal blooms, marine biodiversity loss	Haida Gwaii Experiment (Canada, 2012)
Direct Air Capture (DAC)	High energy use, land and water demand, CO_2 leakage from storage	Clime works (Switzerland/Iceland)
BECCS	Land-use conflicts, habitat loss, food insecurity, monoculture impacts	Drax Power Station (UK, pilot)
Marine Cloud Brightening	Altered precipitation, coastal climate shifts, ocean productivity changes	MCB Pilot Projects (USA/Australia)

4. Case Studies

@2025 International Council for Education Research and Training 2025, Vol. 03, Issue 03,317-331
ISSN: 2960-0006 DOI: https: https://doi.org/10.59231/edumania/9154

To understand the real-world complexity of climate engineering, it is essential to analyze projects that have either been implemented, proposed, or debated in various parts of the world. These case studies provide critical insights into the **scientific feasibility**, **governance failures**, **ethical conflicts**, and **environmental impacts** of climate intervention efforts.

4.1 SPICE Project – United Kingdom (Stratospheric Aerosol Injection Prototype)

Objective: Investigate the feasibility of deploying particles into the stratosphere using a tethered balloon and hose system.

Outcome: Cancelled before physical testing.

Controversy:

Raised ethical concerns about **public consultation**, **patent ownership**, and **experimental governance**.

Criticized for moving ahead without **adequate international dialogue**, highlighting the **governance vacuum** in SRM research.

Lesson: Even small-scale field tests can provoke ethical and political opposition when transparency, consent, and governance are lacking.

4.2 Haida Salmon Restoration Corporation – Canada (Ocean Fertilization)

Objective: Dumped 100 tons of iron sulfate into the Pacific Ocean to stimulate phytoplankton growth and support salmon populations.

Outcome: Created a large algae bloom that reportedly sequestered carbon and increased fish catch in the short term.

Controversy:

Conducted without government or scientific approval.

Violated international agreements (London Convention, Convention on Biological Diversity).

Accused of acting as a **commercial carbon credit scheme** disguised as ecological restoration.

Lesson: Unregulated experiments can risk ecological stability and undermine public trust, reinforcing the need for **binding international legal frameworks**.

4.3 CarbFix Project – Iceland (Direct Air Capture and Mineral Storage)

Objective: Capture CO_2 and inject it into basalt rock formations where it mineralizes into stable carbonates.

Outcome: Highly successful; over 95% of injected CO_2 mineralized in less than two years.

@2025 International Council for Education Research and Training
2025, Vol. 03, Issue 03,317-331
ISSN: 2960-0006
DOI: https: https://doi.org/10.59231/edumania/9154

Significance:

One of the most **environmentally safe and scientifically proven** CDR methods to date.

Operated in partnership with geothermal power plants, offering a **closed-loop carbon solution**.

Lesson: Shows how climate engineering, when **carefully designed and regionally adapted**, can work with nature rather than disrupt it.

4.4 Drax Power Station – United Kingdom (BECCS Pilot Project)

Objective: Convert coal-fired power station to biomass and implement carbon capture technology.

Outcome: Piloted carbon capture systems on small scale; aims for full BECCS integration by 2030.

Controversy:

Biomass sourcing from **foreign forests** (e.g., the U.S.) raises questions about sustainability.

Land use for bioenergy may compete with food security and biodiversity goals.

Lesson: Lifecycle emissions, land use ethics, and global supply chains must be considered before scaling up BECCS.

4.5 Marine Cloud Brightening Trial – Australia and USA

Objective: Test technology to spray seawater into marine clouds to enhance their reflectivity.

Status: Still in experimental phase; small-scale technical trials in California and the Great Barrier Reef.

Potential Benefits:

Could **cool regional climates** (e.g., protect coral reefs from bleaching).

Concerns:

May **alter precipitation patterns** and disrupt marine climate systems.

Lack of regulation for **atmospheric interventions** in international waters.

Lesson: Regional SRM approaches might be feasible, but must undergo **thorough environmental impact assessments**.

4.6 Solar Geoengineering Research Program – Harvard University (USA)

Objective: Explore the physical science of solar geoengineering via the **SCoPEx project** (Stratospheric Controlled Perturbation Experiment).

Planned Activity: Release a small amount of calcium carbonate into the stratosphere from a high-altitude balloon.

Delays and Controversy:

@2025 International Council for Education Research and Training 2025, Vol. 03, Issue 03,317-331
ISSN: 2960-0006 DOI: https: https://doi.org/10.59231/edumania/9154

Public and Indigenous opposition led to the cancellation of initial test flights planned in Sweden.

Criticized for not ensuring **prior informed consent** from affected communities.

Lesson: Even **controlled experiments** without full deployment can face intense public resistance due to lack of transparency and **community inclusion**.

Project	Location	Technique	Key Issue	Lesson Learned
SPICE Project	UK	Stratospheric Aerosol	Ethical, patent, governance concerns	Require global consent and ethical oversight
Haida Gwaii Iron Dumping	Canada	Ocean Fertilization	Unregulated, ecological disruption	Necessity of international legal control
CarbFix Project	Iceland	Direct Air Capture (DACS)	Effective mineralization	Environmentally safe when locally tailored
Drax Power Station (BECCS)	UK	Bioenergy with CCS	Biomass sustainability and land use	Consider entire lifecycle and global impacts
Marine Cloud Brightening Trials	USA/Australia	Cloud Albedo Modification	Potential regional climate impacts	High uncertainty requires controlled, stepwise research
SCoPEx (Harvard Project)	USA/Sweden (planned)	Small-scale SRM experiment	Community resistance and lack of consent	Importance of inclusive, transparent stakeholder dialogue

Policy and Governance Challenges

Lack of global regulation and enforcement mechanisms.

Need for inclusive global treaties similar to the Montreal Protocol.

The possibility of unilateral geoengineering by powerful nations.

Conclusion

Climate engineering offers promising yet perilous possibilities in our battle against climate change. While it may serve as a last-resort strategy, the environmental risks and ethical dilemmas it

@2025 International Council for Education Research and Training 2025, Vol. 03, Issue 03,317-331
ISSN: 2960-0006 DOI: https: https://doi.org/10.59231/edumania/9154

presents must not be underestimated. Cautious, inclusive, and transparent research backed by international governance is essential before any large-scale deployment.

References

1. Buck, H. J. (2016). *Geoengineering: Re-making climate for profit or survival?* Palgrave Macmillan. [ISBN: 978-1137508240].
2. Climeworks. (2023). *Direct air capture and storage: Case studies and global deployment*.
3. Corner, A., Pidgeon, N., & Parkhill, K. (2012). Perceptions of geoengineering: Public attitudes, stakeholder perspectives, and the challenge of "upstream" engagement. *WIREs Climate Change*, *3*(5), 451–466. https://doi.org/10.1002/wcc.176
4. Drax Group. (2023). *BECCS at Drax: Delivering negative emissions for the UK*.
5. https://www.etcgroup.org/content/geoengineering-case-study-haida
6. Fuss, S., Lamb, W. F., Callaghan, M. W., Hilaire, J., Creutzig, F., Amann, T., Beringer, T., de Oliveira Garcia, W., Hartmann, J., Khanna, T., Luderer, G., Nemet, G. F., Rogelj, J., Smith, P., Vicente, J. L. V., Wilcox, J., del Mar Zamora Dominguez, M., & Minx, J. C. (2018). Negative emissions—Part 2: Costs, potentials and side effects. *Environmental Research Letters*, *13*(6), Article 063002. https://doi.org/10.1088/1748-9326/aabf9f
7. Ghosh, A. (2021). Governing solar radiation management: The limits of multilateralism. *Global Environmental Politics*, *21*(1), 68–89. https://doi.org/10.1162/glep_a_00598
8. IPCC. (2022). 2022: Mitigation of climate change. Contribution of working Group III to the sixth assessment report. *Climate change*. Intergovernmental Panel on Climate Change.
9. Lin, A. C. (2013). Does geoengineering present a moral hazard? *Ecology Law Quarterly*, *40*(3), 673–712. https://doi.org/10.15779/Z38JM8T
10. National Academies of Sciences, Engineering, and Medicine. (2021). *Reflecting sunlight: Recommendations for solar geoengineering research and research governance*.
11. Robock, A. (2008). chapters 20 Reasons why geoengineering may be a bad idea. *Bulletin of the Atomic Scientists*, *64*(2), 14–18. https://doi.org/10.2968/064002006
12. Royal Society. (2009). *Geoengineering the climate: Science, governance and uncertainty*. Royal Society.
13. SCoPEx Project—Harvard Solar Geoengineering Research Program. (2023).

@2025 International Council for Education Research and Training 2025, Vol. 03, Issue 03,317-331
ISSN: 2960-0006 DOI: https: https://doi.org/10.59231/edumania/9154

14. Smith, P., Davis, S. J., Creutzig, F., Fuss, S., Minx, J., Gabrielle, B., Kato, E., Jackson, R. B., Cowie, A., Kriegler, E., van Vuuren, D. P., Rogelj, J., Ciais, P., Milne, J., Canadell, J. G., McCollum, D., Peters, G., Andrew, R., Krey, V., . . . Yongsung, C. (2016). Biophysical and economic limits to negative CO2 emissions$_2$ Emissions." *Nature Climate Change*, *6*(1), 42–50. https://doi.org/10.1038/nclimate2870

Received on May 15, 2025
Accepted on June 20, 2025
Published on July 01, 2025