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THE LEGAL CONSEQUENCES OF CLIMATE ENGINEERING (GEOENGINEERING) - ASSESSING ACCOUNTABILITY FOR TRANSBOUNDARY ENVIRONMENTAL HARM UNDER INTERNATIONAL LAW

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ABSTRACT

Climate engineering, commonly referred to as geoengineering, has emerged as a controversial response to the accelerating climate crisis. Techniques such as Solar Radiation Management (SRM) and Carbon Dioxide Removal (CDR) possess the potential to alter global climatic systems beyond national boundaries. While these technologies may mitigate certain effects of climate change, they also present significant risks of transboundary environmental harm, including disruptions to precipitation patterns, biodiversity loss, ocean acidification, and adverse socio-economic consequences. Existing international law has not yet developed a comprehensive framework specifically governing geoengineering activities, creating uncertainty regarding accountability and liability for environmental damage caused by such interventions. This paper examines the legal consequences of climate engineering through the lens of international environmental law, focusing on principles of state responsibility, the no-significant-harm rule, due diligence obligations, and liability for transboundary environmental harm. Drawing upon foundational precedents such as the Trail Smelter Arbitration and the Gabčíkovo–Nagymaros Project case, the paper evaluates whether existing legal doctrines can effectively regulate emerging geoengineering technologies. It further explores the accountability of both states and private actors, assesses the applicability of international criminal law concepts including ecocide, and identifies regulatory gaps within the current legal architecture.

Keywords - Climate Engineering, Geoengineering, Transboundary Environmental Harm, State Responsibility, International Environmental Law, Accountability

INTRODUCTION

The increasing severity of climate change has intensified global discussions regarding alternative methods for reducing greenhouse gas concentrations and limiting global temperature rise. Among the most debated approaches is climate engineering or geoengineering, a broad category of technological interventions designed to deliberately modify the Earth's climatic systems. Geoengineering proposals range from Solar Radiation Management (SRM), which seeks to reflect sunlight away from the Earth to Carbon Dioxide Removal (CDR), which aims to extract greenhouse gases from the atmosphere.Although proponents argue that geoengineering may offer a supplementary tool for combating climate change, critics highlight the possibility of severe unintended consequences. Climatic systems operate on a global scale, meaning that interventions undertaken by one state may affect environmental conditions far beyond its territorial jurisdiction. Alterations in rainfall patterns, agricultural productivity, ocean chemistry, and biodiversity may result in transboundary environmental harm affecting neighboring or distant states. Consequently, questions arise regarding legal accountability when climate engineering activities cause environmental damage.

This paper critically examines the legal consequences of climate engineering under international law. It analyzes the applicability of established principles governing transboundary harm, evaluates the responsibility of states and private actors, and explores emerging debates regarding environmental accountability and ecocide. Through an examination of international jurisprudence and scholarly literature, the paper seeks to determine whether current international law is capable of effectively regulating geoengineering-related environmental harm.

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UNDERSTANDING CLIMATE ENGINEERING AND ITS RISKS

Climate engineering encompasses a variety of technologies aimed at altering climatic processes. The two principal categories are Solar Radiation Management and Carbon Dioxide Removal.

Table 1 - Major Categories of Climate Engineering

Category	Technique	Objective	Potential Risks
Solar Radiation Management (SRM)	Stratospheric aerosol injection	Reflect sunlight and reduce global temperatures	Changes in precipitation patterns, ozone depletion
Solar Radiation Management (SRM)	Marine cloud brightening	Increase cloud reflectivity	Regional climatic disruptions
Carbon Dioxide Removal (CDR)	Direct air capture	Remove atmospheric carbon dioxide	Energy-intensive operations
Carbon Dioxide Removal (CDR)	Ocean fertilization	Enhance carbon absorption by oceans	Marine ecosystem disruption
Carbon Dioxide Removal (CDR)	Afforestation and reforestation	Carbon sequestration	Land-use conflicts and biodiversity concerns

Unlike conventional environmental activities, geoengineering deliberately modifies natural systems on a large scale. The risks associated with these interventions extend beyond national territories and may affect multiple generations. Such characteristics make geoengineering particularly relevant to international environmental law.

THE PRINCIPLE OF NO SIGNIFICANT HARM

One of the most fundamental principles of international environmental law is the obligation of states to prevent activities within their jurisdiction from causing significant environmental harm to other states. This principle emerged through customary international law and has been repeatedly affirmed in international jurisprudence.

The classic articulation of this principle appears in the *Trail Smelter Arbitration*, which established that no state may use its territory in a manner that causes injury to another state through environmental pollution. The tribunal emphasized that states have a duty to prevent activities causing serious transboundary damage. Although the dispute involved industrial emissions crossing the United States–Canada border, the principle has acquired broader significance within international environmental law (Bratspies & Miller, 2011).

Sam Campbell argues that the no-significant-harm principle has evolved to accommodate varying cultural values and environmental priorities while remaining a cornerstone of international environmental governance (Campbell, 2026). In the context of geoengineering, this principle provides an essential normative framework for assessing legality and accountability.

DUE DILIGENCE AND THE DUTY OF PREVENTION

Closely connected to the no-significant-harm principle is the duty of prevention. International law increasingly requires states to exercise due diligence in preventing foreseeable environmental damage. The duty of prevention does not impose strict liability. Instead, it requires states to adopt appropriate measures, conduct environmental assessments, monitor risks, and cooperate with potentially affected states. Due diligence obligations have been recognized in numerous international instruments and judicial decisions.

According to discussions on harm prevention beyond traditional territorial boundaries, modern environmental law has expanded the scope of preventive obligations to address global environmental risks and complex ecological interactions. This evolution is particularly relevant for geoengineering, where impacts may be uncertain yet potentially catastrophic. Environmental Impact Assessments (EIAs) represent a critical mechanism through which states can fulfill due diligence obligations. Before implementing climate engineering projects, states should conduct comprehensive scientific assessments evaluating potential transboundary consequences. Failure to undertake such assessments may constitute a breach of international obligations.

STATE RESPONSIBILITY FOR GEOENGINEERING-RELATED HARM

The doctrine of state responsibility provides the primary legal framework for addressing violations of international obligations. Under customary international law and the Articles on Responsibility of States for Internationally Wrongful Acts (ARSIWA), a state incurs responsibility when conduct attributable to it breaches an international obligation.

Geoengineering projects conducted directly by governments would clearly fall within this framework. If a state's climate intervention activities cause significant transboundary environmental harm, responsibility may arise where due diligence obligations or the no-harm principle have been violated.

Scholars examining state responsibility for environmental harm emphasize that attribution, causation, and proof remain central challenges. Establishing a direct causal connection between geoengineering activities and environmental damage may be difficult because climatic systems are influenced by numerous variables. Nevertheless, advances in climate attribution science may facilitate evidentiary assessments in future disputes (An Ecological Approach to International Law, 2008).

Furthermore, Robert Percival notes that international environmental law increasingly recognizes both responsibility and liability mechanisms for environmental damage, reflecting the growing importance of environmental protection within international legal discourse (Percival, 2020).

LIABILITY OF PRIVATE ACTORS AND CORPORATE ACCOUNTABILITY

While state responsibility remains the primary mechanism for addressing transboundary environmental harm, contemporary geoengineering initiatives increasingly involve private corporations, research institutions, and multinational enterprises. Carbon dioxide removal technologies, direct air capture projects, and ocean-based geoengineering experiments are frequently developed and financed by private entities rather than governments. Consequently, questions arise regarding the accountability of non-state actors whose activities may contribute to environmental harm across national borders (Usman, 2022).

International law has traditionally focused on state obligations; however, the growing influence of private actors in environmental governance has generated demands for broader liability frameworks. Gailhofer and Scherf argue that transboundary environmental harm can no longer be understood solely through state-centric approaches, particularly where multinational corporations possess economic capacities comparable to those of sovereign states (Gailhofer & Scherf, 2022). Geoengineering projects involving large-scale atmospheric or marine interventions illustrate this challenge.

Recent governance scholarship emphasizes that solar geoengineering deployment would require unprecedented institutional oversight because environmental consequences could extend globally (MacMartin et al., 2021). Similarly, Dana, Burns, and Nicholson (2021) contend that governance mechanisms must incorporate accountability structures applicable to both public and private actors. Without such safeguards, victims of geoengineering-related harm may face substantial barriers in obtaining compensation.

The emergence of corporate environmental responsibility, environmental, social and governance (ESG) standards, and transnational environmental litigation suggests a gradual shift toward recognizing broader forms of accountability. Nevertheless, significant legal gaps remain regarding jurisdiction, causation, and enforcement in cases involving climate engineering technologies (Shayegh, 2021).

HUMAN RIGHTS IMPLICATIONS OF GEOENGINEERING

The consequences of climate engineering extend beyond environmental protection and directly implicate internationally recognized human rights. Alterations in precipitation patterns, agricultural productivity, freshwater availability, and ecosystem stability may affect rights to life, health, food, water, housing, and development.

Citro and Smith argue that traditional cost-benefit analyses inadequately capture the human consequences of geoengineering decisions and advocate for a human rights framework as a more appropriate basis for governance (Citro & Smith, 2021). Such an approach emphasizes the protection of vulnerable populations rather than solely evaluating aggregate economic benefits.

Small island developing states provide a particularly compelling example. Lefale and Anderson note that these states are disproportionately affected by climate change and may also face unique vulnerabilities arising from geoengineering interventions (Lefale & Anderson, 2018). Decisions regarding climate engineering are often made by technologically advanced states, while the associated risks may be borne by geographically distant communities with limited political influence (Robbins, 2021).

Jegede's analysis of Carbon Dioxide Removal projects highlights the importance of integrating human rights considerations into climate intervention strategies. Such integration ensures that technological solutions do not undermine fundamental rights while pursuing environmental objectives (Jegede, 2021).

GEOENGINEERING, ECOCIDE, AND INTERNATIONAL CRIMINAL LAW

The growing severity of environmental degradation has stimulated debates regarding the recognition of ecocide as an international crime. Although geoengineering is generally proposed as a mechanism for mitigating climate change rather than causing harm, poorly designed or recklessly implemented interventions could potentially generate severe environmental damage.

Rahman and Kaur observe that international criminal law increasingly engages with environmental harm, particularly where damage is widespread, long-term, and severe (Rahman & Kaur, 2024). Similarly, Hossain argues that ecocide may provide a valuable framework for addressing serious environmental destruction that threatens ecological systems and human communities (Hossain, 2025). Karen Scott's analysis of geoengineering ethics highlights the dangers associated with deliberate planetary manipulation and warns that technological interventions

may create novel forms of environmental injustice (Scott, 2015). These concerns strengthen arguments for establishing robust accountability mechanisms before deployment occurs.

Contemporary climate litigation has expanded environmental accountability beyond traditional state responsibility. In *Urgenda Foundation v. State of the Netherlands*, (ECLI:NL:HR:2019:2007), the Court required stronger climate action to protect human rights. The Court adopted a similar approach in *Neubauer v. Germany*, *BVerfG* (1 BvR 2656/18 (2021)), emphasizing intergenerational equity.

Corporate accountability was advanced in *Milieudefensie et al. v. Royal Dutch Shell plc (*C/09/571932 / HA ZA 19-379), which required emissions reductions from a private corporation. Similar reasoning appears in Friends of the *Irish Environment CLG v. Government of Ireland (*[2020] IESC 49) and *Held v. State of Montana* (No. CDV-2020-307 (Mont. Dist. Ct. 2023)), where courts linked environmental protection to constitutional and human rights obligations.

Nevertheless, current international criminal law remains limited in addressing geoengineering-related harm. Existing crimes under the Rome Statute focus primarily on armed conflict and do not comprehensively regulate environmental damage occurring during peacetime. Consequently, legal reform may be necessary if geoengineering technologies become widely deployed (Ferrari, 2021).

Table 2 - Accountability Mechanisms Applicable to Geoengineering Harm

Legal Framework	Basis of Liability	Relevant Actors	Challenges
State Responsibility	Breach of international obligations	States	Attribution and causation
Civil Liability	Negligence or strict liability	Corporations and private entities	Jurisdictional limitations
Human Rights Law	Violation of protected rights	States and regulated actors	Enforcement difficulties
Environmental Treaties	Non-compliance with treaty obligations	States	Fragmented regulation
Proposed Ecocide Framework	Severe, widespread environmental destruction	States and individuals	Lack of universal recognition

EXISTING INTERNATIONAL LEGAL FRAMEWORKS GOVERNING GEOENGINEERING

Despite growing interest in climate engineering, no comprehensive international treaty specifically regulates geoengineering activities. Instead, governance relies upon a fragmented collection of environmental principles, treaty obligations, and customary international law. Reynolds argues that existing international law provides partial governance mechanisms but remains insufficient for addressing the unique challenges presented by climate engineering (Reynolds, 2018). Relevant legal frameworks include the United Nations Framework Convention on Climate Change (UNFCCC), the Convention on Biological Diversity (CBD), the United Nations Convention on the Law of the Sea (UNCLOS), and customary principles governing transboundary harm. The evolution of climate engineering research demonstrates how scientific developments have outpaced legal regulation (Lawrence & Crutzen, 2018). Early discussions focused primarily on technical feasibility, whereas contemporary debates increasingly emphasize governance, accountability, and risk management.

Ayers (2014) notes that geoengineering research has expanded rapidly across multiple disciplines, reflecting increasing recognition of its potential significance. Similarly, Szerszynski and Galarraga (2013) emphasize the interdisciplinary nature of climate engineering research and the need for governance approaches capable of integrating scientific, legal, ethical, and social perspectives.

The legal principles governing accountability for geo-engineering can be traced to landmark environmental decisions. In *Trail Smelter Arbitration (United States v. Canada)* (3 R.I.A.A. 1905 (1941)), the tribunal established the no-harm principle, holding that states must prevent activities within their jurisdiction from causing transboundary environmental damage. The International Court of Justice reaffirmed environmental protection concerns in *Gabčíkovo–Nagymaros Project (Hungary v. Slovakia)* (Judgment, I.C.J. Reports 1997, p. 7), where sustainable development was recognized as a guiding principle in balancing environmental and developmental interests.

More recently, *Request for an Advisory Opinion Submitted by the Commission of Small Island States on Climate Change and International Law, Advisory Opinion* (ITLOS Case No. 31 (2024)) strengthened due diligence obligations regarding climate-related harm, while the *Advisory Opinion on the Obligations of States in Respect of Climate Change* (I.C.J. (2025)) emphasized state responsibilities under international law for environmental protection.Some scholars question whether existing climate institutions should regulate geoengineering. Reynolds (2018) argues that organizations such as the UNFCCC and CBD may not be ideally suited for governing solar climate engineering because their mandates were not designed for intentional climate modification. This perspective has contributed to calls for specialized international regulatory frameworks. Recent scholarships further emphasize the need for anticipatory governance. Gabriel and Low (2018) argue that foresight mechanisms are essential for evaluating long-term consequences before deployment occurs. Such approaches align closely with precautionary principles embedded within international environmental law (Burns et. al., 2021).

THE GABČÍKOVO–NAGYMAROS CASE AND SUSTAINABLE DEVELOPMENT

The decision of the International Court of Justice in the Gabčíkovo–Nagymaros Project case remains highly relevant to contemporary geoengineering debates. The dispute concerned a hydroelectric project jointly undertaken by Hungary and Slovakia and raised important questions regarding environmental protection and sustainable development (Chavez, 2021). Subsequent analyses have emphasized the relationship between the Gabčíkovo–Nagymaros judgment and broader principles of international environmental law. The Court recognized the importance of balancing economic development with environmental protection, thereby reinforcing the concept of sustainable development (Dana, 2022).

The case is particularly significant because it demonstrated judicial willingness to consider evolving environmental norms when interpreting international obligations. Through the Looking Glass, Sustainable Development and Other Emerging Concepts of International Environmental Law in the Gabčíkovo-Nagymaros Case and the Trail Smelter

Arbitration highlights how international law has progressively incorporated environmental considerations into traditional legal doctrines (Davies, 2025).

Geoengineering governance requires a similar balancing exercise. While climate intervention technologies may contribute to climate mitigation, they also pose substantial environmental risks. The principle of sustainable development therefore requires careful evaluation of both benefits and harms before deployment decisions are made.

CONCLUSION

Climate engineering represents one of the most ambitious and controversial technological responses to climate change. While geoengineering may offer potential benefits in addressing rising global temperatures, it simultaneously creates unprecedented risks of transboundary environmental harm. Existing principles of international environmental law, including the no-significant-harm rule, due diligence obligations, state responsibility, precaution, and sustainable development, provide an important foundation for assessing accountability. The continuing relevance of the Trail Smelter Arbitration and the Gabčíkovo–Nagymaros judgment demonstrates that international law already possesses valuable normative tools for addressing cross-border environmental risks.

However, geoengineering introduces challenges that existing legal frameworks were not specifically designed to address. Questions of causation, attribution, jurisdiction, compensation, corporate liability, and human rights protection remain insufficiently resolved. The absence of a dedicated international regulatory framework creates significant uncertainty regarding accountability for environmental damage arising from climate interventions. Emerging discussions concerning ecocide further illustrate the growing recognition that severe environmental harm may require stronger legal responses.

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