

Climate-Geoengineering as Development: Applying the
Capabilities Approach to Climate Responses in South- Asia

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by examiners.

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Abstract

The significant range of climate change impacts and capacities to address climate change demands that responses be diverse and indigenized through a democratic process. In the case of climate geoengineering (CGE), the predominant views have come from scholars from the global North who have explored CGE research based on their perspectives and developed states' political and economic contexts. As the discussion surrounding CGE moves from the periphery to the center of climate policy debates, there is a need for more scholars from the global South to come forward and apply perspectives and theoretical lenses informed by the conditions experienced in the global South to the debates on CGE research and governance. Framing CGE as a set of climate responses that address the needs and values of the global South may increase the salience of these debates for developing countries. To this end, this dissertation develops a theoretical framework for examining CGE based on Amartya Sen's capabilities approach. Then, it applies this framework to two case studies addressing the relationships between CGE and South Asia's development context.

In the theoretical chapter, I argue that it is important to reframe CGE in a way that is more likely to align with the broader development aspirations of the global South. Reframing CGE as a development is a difficult task because development is a contested term with multiple meanings. Therefore, I consider Sen's idea of "development as freedom" and explore CGE through Amartya Sen's capability framework to analyze whether CGE can be of potential use for protecting and advancing human capabilities threatened due to climate change. The theory of capabilities offers a promising framework that can provide an ethical foundation for analyzing the interface of developing countries with CGE research and governance. The capability approach is rooted in the reality of the global South. The justice-oriented capability framework emphasizes human autonomy, which looks at practical capabilities to attain individual and collective ends.

The first case study examines the link between Carbon Dioxide Removal (CDR) and development under China's transnational development initiative, namely the Belt and Road Initiative (BRI) in Pakistan. BRI is seen as a crucial enterprise for economic development by policymakers of many developing countries. However, simultaneously, BRI can compromise the emission reduction goals of host countries, which they committed to under the Paris Agreement. Pakistan is one of the most significant participants of the BRI, with numerous coal-fired energy projects sponsored by China under the BRI. Pakistan also has ambitious emission reduction goals demonstrated through its Nationally

Determined Contributions (NDCs) and an internationally celebrated afforestation and reforestation project like the Billion Tree Tsunami (BTS). This case study examines whether CDR initiatives can be integrated into modern development structures like the BRI and the associated governance challenges. The key findings point to the limited degree that the BRI structure has engaged with CDR, notwithstanding the acknowledgment of the need to “green” the BRI. CDR holds potential as a source of just climate development, but the top-down structure of the BRI limits the democratic values that lie at the center of Sen’s approach to development (as freedom).

In the second case study, I analyze the case of targeted geoengineering for protecting and preserving the rapidly melting glaciers in the Himalayas, Karakoram, and Hindukush (HKHK) in South Asia. These rapidly melting glaciers can cause floods and food insecurity in the region and reduce the capabilities of the people to pursue development. The imperative of glacier preservation is recognized by the United Nations General Assembly Resolution in designating 2025 as the International Year of Glacier Preservation. In South Asia, the mountain ranges of HKHK present a case for glacier preservation because of the extreme importance of these glaciers for the water, food, and energy security of the region's people, making glacier preservation a key development issue. This chapter examines whether targeted geoengineering can protect development under threat due to climate-induced disasters in the HKHK region. The idea of targeted geoengineering has been primarily explored in the context of Arctic intervention to preserve and protect the polar ice, but the urgency of glacier preservation in South Asia underlines the importance of examining new climate responses. The case study applies the capabilities framework to consider the normative and governance dimensions of glacier preservation. This case study is more exploratory, given the high degree of uncertainty surrounding approaches to glacier preservation. The chapter seeks to identify a set of governance principles consistent with the capabilities approach that may guide the complex cooperation and governance challenges that regional glacier preservation would entail.

The conclusion revisits the merits of framing CGE as an emerging element of development discourses.

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Dedication

"To my beloved parents, my mother, Razia Begum, and my late father, Azmat Hussain Chattha."

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List of Acronym and Abbreviations

ADB	Asian Development Bank
AIIB	Asian Infrastructure Investment Bank
AR	Afforestation and Reforestation
B3	Build Back the Better World
BECCS	Bioenergy with Carbon Capture and Storage
BR&Cs	Belt and Road Countries
BRI	Belt and Road Initiative
BRICS	Brazil, Russia, India, China, and South Africa
BRIGC	BRI International Green Development Coalition
CAS	Chinese Academy of Sciences
CBD	Convention on Biodiversity
CBDR	Common but Differentiated Responsibilities
CCS	Carbon Capture and Storage
CCT	Cirrus Cloud Thinning
CDB	China Development Bank
CDM	Clean Development Mechanism
CDR	Carbon Dioxide Removal
CGE	Climate geoengineering
COP	Conference of Parties
CPEC	China Pakistan Economic Corridor
DACCS	Direct Air Carbon Dioxide Capture & Storage
EIA	Environmental Impact Assessment

ENMOD	Environmental Modification Convention
ESCAP	Economic and Social Commission for Asia and the Pacific
ESIs	Earth System Interventions
ESPRC	The Engineering and Physical Science Research Council
EW	Enhanced terrestrial weathering
EXIM	China Export-Import Bank
FAO	Food and Agricultural Organization of the United Nations
FDIs	Foreign Direct Investments
GBAM	Ground-Based Albedo Modification
GDP	Gross Domestic Product
GEG	Global Environmental Governance
GGR	Greenhouse Gas Removal
GHG	Greenhouse Gas Emissions
GLENS	Geoengineering Large Ensemble Project
GLOF	Glacial Lake Outburst Flood
GMOs	Genetically Modified Organisms
GtCO ₂	Gigaton of Carbon Dioxide
HDI	Human Development Index
HDR	Human Development Report
HKHK	Himalaya, Karakoram, and Hindu Kush
IAMs	Integrated Assessment Models
ICIMOD	International Centre for Integrated Mountain Development
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
KPK	Khyber-Pakhtunkhwa

KTN	Kilo Tonn
LDCs	Least Developing Countries
MCB	Marine Cloud Brightening
MCSD	Multistakeholder Dialogue
MDGs	Millennium Development Goals
MENA	Middle East and North Africa
MOUs	Memorandum of Understandings
MSR	Maritime Silk Road
MW	Mega Watt
NDCs	Nationally Determined Contributions
OCCS	Ocean carbon capture and storage
ODA	Official Development Assistance
OIF	Oceans Iron Fertilization
RMC	Regional Member Countries
SAARC	South Asian Association for Regional Cooperation
SACEP	South Asia Co-operative Environment Programme
SAI	Stratospheric Aerosol Injection
SDGs	Sustainable Development Goals
SIDS	Small Island Developing States
SKLCS	State Key Laboratory of Cryospheric Science
SREB	Sill Road Economic Belt

Preface

Two events can help readers to understand my motivation to write this dissertation. In December 2022, I read a social media post that Janos Pastor, Executive Director of the Carnegie Climate Governance Initiative (C2G), would lecture about SRM in Islamabad (Pakistan). I was excited to see that post on social media because I was working on CGE and had benefited from reports and workshops developed by C2G. The workshop's title was "Managing the Risks from Increasingly Likely Overshoot of the 1.5 C Goal role (if any) of Solar Radiation Modification." When I reached the venue, the room was full of policymakers, researchers, and journalists working on climate change. Janos Pastor spoke at length about CDR and SRM, but his primary focus was SRM. However, the most exciting part of the lecture was the question-and-answer session.

The questions suggested that most participants did not understand the basic ideas about CDR or SRM. Most participants were concerned about CGE's role as a potential climate policy option and its implications for the climate justice movement. One of the participants asked Janos Pastor if SRM was a security technology and if a superpower was involved in promoting this technology. Janos answered "no" to this question. This question reminded me of my research journey regarding CGE for my Ph.D. dissertation. Before my Ph.D., I worked in the Ministry of Climate Change in Pakistan for two years. I was able to attend some of the critical national and international climate change-related negotiations and events. However, until my comprehensive exams, I was unfamiliar with CGE. Despite working in climate change, many people like me from the global South still lack a basic understanding of CGE and its implications for developing countries.

The second event was listening to a speech by a politician from Pakistan concerning the Thar coal reserves, one of the largest coal reserves in the world, and their role in attaining energy security in Pakistan. He discussed the China-Pakistan Economic Corridor (CPEC) and how CPEC was helping Pakistan to explore coal reserves in Thar and provide cheap energy to the people of Pakistan. He described the Thar coal reserves as black gold for Pakistan. Watching support for coal-fired energy from Pakistan's political leadership in 2023 is intriguing, as Pakistan has committed to curtailing its emissions under the Paris Agreement 2015. How can Pakistan reduce emissions if it continues to increase coal-fired energy? Is there a juxtaposition between technological solutions to remove carbon and relying on coal-fired energy? Will developing countries' development needs remain dominant compared to their emission reduction commitments under the Paris Agreement?

Although these two events occurred at the end of my dissertation, they aptly describe the context that inspired me to write my Ph.D. dissertation on CGE in South Asia. On the one hand, developing states are necessarily focused on economic development and improving the well-being of their people. On the other hand, developing countries are increasingly considered responsible for growing contributions to climate change and may benefit from new climate technologies and potentially be put at risk. Despite the centrality of CGE to future climate responses, developing countries view these technologies with suspicion and of limited relevance to their circumstances. A reframing is required to allow the global South to assess CGE technologies from a meaningful perspective for their lives and in line with economic realities.

Chapter 1: Introduction

Engagement of the Global South in CGE Debates

Paul Crutzen's seminal work regarding albedo enhancement by stratospheric sulfur injections ushered in a debate on CGE as a potential response option to address the issue of climate change. Crutzen argued that geoengineering needs to be researched because addressing climate change through emission reductions alone appears daunting under existing technological and economic conditions (Crutzen, 2006). The Royal Society has defined CGE "as the deliberate large-scale intervention in the earth's climate system to moderate global warming" (The Royal Society, 2009, P.ix). Intergovernmental Panel on Climate Change (IPCC), in its report (2018) on global warming of 1.5 °C, identifies four distinct responses to manage climate change: mitigation, adaptation, carbon dioxide removal, and solar radiation modification.¹ CGE, as used in this dissertation, consists of the two baskets of technologies. CDR addresses dangerous carbon dioxide levels by removing carbon dioxide directly from the atmosphere. SRM addresses the increase in global average temperature through interventions that reflect the sunlight away from the earth's atmosphere. More recently, SRM has been further classified into global SRM, which impacts the global energy balance (and thereby impacts global average temperatures) and targeted geoengineering. Targeted geoengineering uses sunlight reflection methods or other engineering approaches on a localized scale to protect a particular environmental feature or condition (such as sea ice or glaciers) (Bodanky & Hunt, 2020; Moore et al., 2020). There are, of course, significant differences between CDR and SRM technologies that merit their distinct treatment. However, these technologies can also be implemented as part of a portfolio of climate responses that each address different global and state action dimensions to achieve the temperature targets under Article 2 of the Paris Agreement (Cao et al., 2017).

CGE deserves special consideration regarding the global South because of the extreme vulnerability of developing countries due to climate change and the limited financial and technical capacity of developing countries to address climate change. In addition, CGE can potentially increase political and

¹ Solar CGE is described with various names like Solar Radiation Modification (IPCC, 2018) or Solar Radiation Management (The royal Society, 2009) or Solar Climate Engineering (Reynolds, 2016). I will use Solar Radiation Modification (SRM) in this research work.

governance disturbances at the global level (Parson, 2014). For example, extreme weather events, whether attributable to SRM or not, may create a situation where countries or regions blame each other for mishandling SRM experiments or deployment and demand compensation (Honegger et al., 2018). The issue of compensation due to any harm caused by CGE is likely to be one of the most contentious issues in CGE governance (Honegger et al., 2018). CGE comprises a range of climate interventions, and each technology may require different compensation mechanisms. CGE research and governance may have different outcomes in developing countries than in developed countries because of different social, economic, and political scenarios (Sugiyama et al., 2020). Most of the research regarding CGE is at an early stage, but "there is broad agreement within the scientific community that North-South², South-South and triangular regional and international cooperation is crucial when further exploring and researching carbon removal and solar CGE." (Honegger et al., 2018, p.35). Cooperation, respective capabilities, and access to information are also vital factors in the responsible advancement of CGE research (Hubert, 2018).

Developing countries' environmental considerations are quite different from those of developed countries. Development is crucial for the global South as it often overshadows other pressing issues like climate change in their national priorities. CGE governance may be better analyzed for the global South if there is due consideration of the local circumstances of developing countries. Legal and ethical divisions in global environmental governance have reinforced the sense of solidarity among developing countries. The expression of "global South" within global environmental politics reflects a desire for developing countries to share a collective identity and negotiate environmental issues (Najam, 2005). However, the term global South is not a static concept, but it has embraced influence from various geographies, disciplines, and scholarly and academic debates (Clarke, 2018). Despite being vague, the global South is a powerful expression to reflect the inequality between developed and developing communities (Clarke, 2018). Developing countries have diverse environmental concerns and capabilities to meet their environmental challenges.

The timely participation of developing countries in CGE debates can help them deliberate about CGE's feasibility and desirability according to their local circumstances. Participatory freedom also highlights

² In global environmental politics, the global North is considered North America, Western Europe, and developed parts of Asia, while the global South is considered Africa, South America, and developing parts of Asia (Uddin, 2017). Besides this fundamental geographical division, the global North and global South are divided by scholars and policymakers based on political stability, technological advancement, and economic growth (ibid). However, in this proposal the global South refers to China and developing countries of Asia, which are part of G77+China² in the United Nations (UN). There are other groups least developing countries (LDCs), small island developing states (SIDS) but the focus of this dissertation is the G77+ China.

people's social and economic conditions in developed and developing countries. Similarly, the role and contribution of CGE in national policymaking will vary from country to country. These local conditions remain relevant when national governments develop plans to address anthropogenic climate change or poverty. The risk assessment of developing countries in the wake of climate change may differ from developed countries. One crucial difference between developed and developing countries is the nature and intensity of risk people are willing to take due to their economic considerations. While citing an example from India's western Bengal, Amartya Sen outlines how villagers risk their lives because of tiger attacks and yet collect honey daily from the jungle for their earnings. Sen (1999) contends that an enormous risk to human lives from Tigers is:

Just one illustration of the force of economic needs in many third-world countries. It is not hard to feel that this force must outweigh other claims, including political liberty and civil rights. If poverty drives human beings to take such terrible risks—and perhaps to die terrible deaths—for a dollar or two of honey, it might well be odd to concentrate on their liberty and political freedoms. Habeas corpus may not seem like a communicable concept in that context. Priority must surely be given, so the argument runs to fulfilling economic needs, even if it involves compromising political liberties. It is not hard to think that focusing on democracy and political liberty is a luxury a poor country cannot afford (Sen, 1999, pp. 146-147).

This story suggests how deeply Amartya Sen values human welfare and the protection of capability in the wake of challenges like poverty and hunger. The history of global environmental governance suggests that negotiators have often shown sensitivity towards the different nature of issues faced by rich and developing countries. Many environmental and climate change-related agreements explicitly mention the inequality between developing and developed countries. Perhaps the most important one is the United Nations Framework Convention on Climate Change (UNFCCC), signed at the Earth Summit in Rio de Janeiro (1992), which places different emission reduction responsibilities on Annex-I (developed) and non-Annex-II (developing) countries. Moreover, one of the most prominent principles of international environmental law, Common but Differentiated Responsibilities (CBDR), also reflects a global divide regarding the responsibility to deal with climate change. This recognition of the different positions of developed and developing countries suggests not only that the global South is an essential stakeholder in designing climate policy options, including CGE, but that its position on these issues will reflect the distinct responsibilities and capacities of the global South.

Reframing CGE as a Means of Development (Enhancing Capabilities)

I analyze CGE as a set of potential climate policy options for developing countries from the capability approach perspective. "Given the lack of existing knowledge of geoengineering, public acceptance is highly susceptible to how these technologies are framed, offering both risks and opportunities for climate communication" (Raimi, 2021, p. 66). The specific framing of CGE can be a vital point in understanding the awareness of different stakeholders regarding CGE (Corner et al., 2011). Developing countries may consider CGE research and governance more seriously if it can help them to attain development and protect capabilities threatened due to climate change. People in the global South are suffering from climate change, and the levels of poverty, climate-induced disasters, and climate migrations are increasing. The massive floods in Pakistan in 2022 reflect how vulnerable developing countries are because of climate-induced disasters. It is not just that developing countries have to protect their development from climate change, but they also have to seek new development to avoid the poverty trap (World Bank, 2022). It reflects the dilemma of developing countries as they need to accelerate development, but it should be low-carbon development. If developing countries increase their reliance on fossil fuel-based development, it compromises their ability to honor international commitments to reduce emissions. Developing countries have less ability to decarbonize their economies because of economic and technological constraints without the help of developed countries (World Bank, 2022). An interviewee (N) stated that:

People in the global South that are suffering the impacts of climate change want to have every possible solution investigated and, on the table. I don't think they have some what I would call a fantasy view about humans being a special part of viewing nature as some kind of virgin on a pedestal to be never violated. That's just simply not how people in the developing world live and work. So, I think there's a huge amount of what can I say, naivety or delusional thinking in much of the North, particularly North America, about the concept of nature and wilderness. And I think that is going to be leading to a lot of problems.

Developing countries face a trade-off between climate actions and growth development (World Bank, 2022). If we look at CGE as a means of development for protecting capabilities threatened due to climate change, things can be seen more precisely from the perspective of developing countries concerning CGE research and governance. For example, the global South has different cultures and societal values than developed countries. "Public policy, like politics, is the art of the possible, and this is important to bear in mind in combining theoretical insights with realistic readings of practical

feasibility" (Sen, 1999, p.132). Amartya Sen emphasizes that public policy, like politics, must balance idealism with pragmatism, focusing on what is realistically achievable. While theoretical insights provide valuable guidance, they must align with practical feasibility to be effective. Policies should aim for real-world impact, considering constraints like resources and political will. The art lies in merging aspiration with actionable implementation.

The global South differs from the global North and has distinct environmental issues. The peculiar nature of climate change events and their impacts on the population demands that climate policies, including CGE, be customized. The agency of the global South in determining and designing their climate policies is crucial to attaining the emission reduction targets set in the Paris Agreement. Global South, too, has several concerns regarding CGE research. For example, CGE may slow down the global North's efforts concerning emissions reduction. Then, there are chances of overshooting the Paris temperature targets due to late reliance on CDR and having to draw down CO₂ levels (IPCC, 2023). Concerning SRM, there are concerns that sudden termination of SRM may impact precipitation patterns and monsoons if SRM is deployed recklessly, and more disasters could happen (Robock et al., 2010). These concerns of the global South concerning CGE make it challenging to pursue CGE research in the global South. Given the complex nature of CGE research and governance, it will not be easy for developing countries to allow or restrict any technology under the ambit of CGE without thoroughly evaluating each approach's financial, technical, and social aspects.

Why is this Research Project Important and Necessary?

This project is important for several reasons. First, because CGE is inherently distributive, there is a need for an equity-based framework for allocating the burdens and benefits of CGE. Equity also highlights the importance of accountability, transparency, and liability. It would be appropriate to have a detailed discussion on the governance of SRM because of its large-scale security and political implications. Second is the capacity rationale; although CGE is getting more and more attention from scholars and policymakers, there is a question about the capacity of scholars and policymakers from the global South to effectively engage in dialogue and debates about CGE because of their limited engagement in GE research and debates (Rehman et al., 2018). Scientific expertise concerning low-carbon technologies is primarily based in developed countries and China (World Bank, 2022). Therefore, developing countries depend on developed countries to seek knowledge and technology transfer for low-carbon development. Developing countries need capacity building to engage with

developed countries meaningfully and the capacity to assess viability concerning CGE research and governance. Finally, inaction about climate change is costlier than researching for CGE and dealing with its potential adverse effects. According to the World Bank:

Although climate policies may be positive in aggregate, they can have large negative impacts on certain communities, sectors, or regions, and it is important to minimize, manage, or compensate for these. Most of the Country Climate and Development Reports (CCDRs) find that countries can compensate for the impact of climate policies on poor people at a low cost compared to the large financial, economic, and environmental costs of inaction. (World Bank, 2022)

This research project broadens the existing debates concerning CGE research and governance in the context of developing countries. Developing countries can have implications for not analyzing all climate policy options while considering their domestic circumstances and the gravity of climate change in the region. The connection between development and CDR is not fully understood. It needs further attention, especially in the context of China's Belt and Road Initiative (BRI), its impact on emission increase, and the potential scenario for CDR as a climate policy option. There are many concerns that transnational development projects like BRI and Build Back Better World (B3W) may compromise the emission reduction efforts of the host countries. It highlights a link between investment and development towards emission increase where CDR might be a possible climate policy option for the host countries.

Another development aspect is protecting the existing development initiatives by avoiding climate-induced disasters. The targeted geoengineering focused on protecting HKHK glaciers in South Asia is also part of this dissertation. Targeted geoengineering differs from global SRM as it has different implications from global SRM. Targeted geoengineering does not impact worldwide temperature and precipitation. Targeted geoengineering looks more like an adaptation, and there are some significant parallels between targeted geoengineering and global SRM. Targeted geoengineering is important for transnational issues of water security through glacier protection. There may be distributive issues if glacier changes affect water distribution among countries (World Bank, 2022). Both case studies, first about the feasibility of CDR under the BRI and second about targeted geoengineering in South Asia, are part of this dissertation and analyze CGE to advance or protect development under threat due to climate change. These two case studies can help to comprehend the reframing of CGE in developing countries, especially in South Asia. These case studies address the broader question of this dissertation: "Can CGE be used to advance development?"

Overview of CGE

CDR and SRM collectively are also known as CGE. I use the term CGE to collectively refer to three types of climate interventions: CDR, SRM, and targeted geoengineering. CGE is a "deliberate intervention in the planetary environment of a nature and scale intended to counteract anthropogenic climate change and its impacts" (CBD, 2016, p.8). This definition highlights the role of CGE as a potential option to deal with anthropogenic climate change and its impacts. The following are some crucial observations of the IPCC (2018) concerning CDR and SRM, which are essential for understanding each approach and its discussion in this chapter. First, CDR and SRM are two different approaches. CDR is about removing existing carbon emissions from the atmosphere, while SRM is about reducing the heat on Earth by reflecting or reducing the incoming sunlight. Second, all net emission reduction strategies must follow pathways to limit the global average temperature by 1.5 °C with limited or no overshoot. However, CDR is essential in different amounts in all pathways because it removes rather than reduces emissions. Third, limiting global warming by 1.5 °C requires significant adjustments in our energy systems, infrastructure, and lifestyles. The lifestyle change will require much effort and sacrifice, for which every country will not be ready, so CDR and SRM would offer to make fewer rapid changes. Fourth, some scientific models suggest the feasibility of SRM for attaining 1.5 °C; however, there are many ethical, physical, and technical uncertainties about the future deployment of SRM.

IPCC has identified three roles for CDR in its AR6: substituting for emission reductions, addressing hard-to-abate emissions, and drawing down CO₂ to prevent and reduce overshoot. (IPCC-AR6, 2023). Then, there are some key governance points in the case of CDR research and deployment, like some key technologies that require capacity and financing. Since CDR will play a crucial role in future carbon markets, CDR is a possible source of development, but the distribution of CDR is very uncertain. The global distribution of CDR potential does not match prevailing equity considerations (Pozo et al., 2020). The Paris Agreement's approach to mitigation (CDR is mitigation) allows for a bottom-up approach for CDR. However, states may face pressures to adopt CDR because of their local situations' social and cultural dimensions. The role of co-benefits of CDR approaches like bioenergy with carbon capture and storage (BECCS) (removing CO₂ by growing feedstock for use in bioenergy plants, combined with capturing and storing the emissions from the plant) removes carbon and contributes to energy production. The issue is not whether states will engage in CDR or not, but the issue is how

they will provide finance and what type of CDR states can use. There are further issues - in terms of who will benefit, availability of co-benefits, impact of CDR on other activities and resources.

In the case of SRM, some states may be worse off, unlike CDR, where states can decide for themselves (Nicholson, 2020). SRM requires broad global agreement, and some provisions of international law may have relevance to this situation (Geden & Dröge, 2019). From a freedom perspective, CDR provides for choice at the state and possibly local levels, whereas SRM removes choice and places it in the hands of some other international body we do not know - and cannot dismiss the concerns that may get out of control. A contentious option concerning CGE governance is placing a complete moratorium on large-scale SRM activities and restricting any government financial support to these initiatives. SRM technologies are still in their infancy, and more research and consultation are required before deployment (IPCC, 2018). In 2022, scholars from various countries initiated a petition named "Solar-Geoengineering Non-Use Agreement." These scholars asked the world governments to stop supporting SRM research because it is risky and causes distraction from mitigation efforts (Biermann et al., 2021). There is skepticism about the validity and feasibility of CGE as a climate response because of the lack of scientific evidence in managing climate change, especially SAI, which "is undesirable, ungovernable and unreliable" (Hulme, 2014, P.xii). According to Biermann et al (2021, p.4):

Without effective global and democratic controls, the geopolitics of possible unilateral solar geoengineering deployment would be frightening and inequitable. Given the anticipated low monetary costs of some of these technologies, there is a risk that a few powerful countries would engage in solar geoengineering unilaterally or in small coalitions, even when most countries oppose such deployment.

However, some scholars are not defensive or apologetic about CGE's research and deployment and believe this is the right time to study CGE (Parson et al., 2024). The proponents of SRM research believe "that, as a society, we have reached a point where the severity of the potential risks from climate change appears to outweigh the potential risks from the moral hazard associated with a suitably designed and governed research program" (NAP, 2015(b), p. 8).

There is the possibility that an argument for a non-use agreement still needs more work to reflect some crucial concerns of developing countries regarding climate policy options. On the other hand, targeted geoengineering uses some of the similar mechanisms as global SRM, such as surface albedo modification. It may involve some other engineering techniques, but not globally. "Targeted geoengineering aims to tackle a global scale impact of climate warming by addressing local or regional

systemic interventions” (Moore et al.,2020, p.108). Some scholars would argue that targeted geoengineering is not a CGE that speaks to scale as a core part of the definition (Bodansky & Hunt, 2020). The scale of targeted geoengineering proposals is not specific; some applications could involve multiple states and massive engineered solutions. There are some common governance questions between targeted and global geoengineering, like who contributes, who is responsible, and how to manage. For example, targeted intervention in the Arctic to limit ice melting may involve many Arctic countries, and the governance questions are beyond the realm of one single state. Differentiating between types of CGE is not always clear, but the question of scale is critical.

The rationale behind looking at all climate interventions in this dissertation is to provide a theoretical foundation for understanding climate interventions through the capability lens. The core motivation behind each climate intervention is to look beyond adaptation and mitigation options and explore if technology can help to address climate change in an ethically acceptable manner that accounts for specific goals, concerns, and capacities of the global South. As climate interventions are large in number and diverse, it is appropriate to analyze them through a single theoretical framework for studying them as just climate interventions in a development context. One possible reason is to compare various CGE approaches and have a common metric for governance and evaluation. Another might be to create commonality across all climate responses. Mitigation (reductions) and adaptation already account for development concerns, providing a more inclusive and integrated approach. Some of the most authoritative geoengineering reports have considered CDR and SRM together while maintaining the technological difference between the two approaches (The Royal Society, 2009; IPCC, 2018; The NAP,2018; CBD, 2016). IPCC (2018) has also reviewed CDR and SRM as potential approaches for attaining the Paris Agreement's targets, and it has concluded that both approaches should be evaluated in the current situation to restrict global warming by 1.5 °C. In addition, the IPCC (2018) maintained that limiting the increase in temperature and reducing carbon emissions are interlinked, and both are urgent matters and require immediate action. "CDR would be used to compensate for residual emissions and, in most cases, achieve net negative emissions to return global warming to 1.5°C following a peak” (IPCC, 2018, p. 19). On the other hand, a "large-scale SRM could potentially be used to supplement mitigation in overshoot scenarios to keep the global mean temperature below 1.5°C and temporarily reduce the severity of near-term impacts” (IPCC, 2018, p.71). These observations from IPCC indicate that CDR, SRM, and targeted geoengineering may complement each other in specific scenarios.

The peak-shaving approach is the joint deployment of adaptation, mitigation, CDR, and SRM. The peak-shaving scenario depends on each approach's pattern and proportionate deployment (Asayama & Hulme, 2019). A prominent argument favoring stratospheric aerosol injection (SAI) is buying more time for adaptation and mitigation measures. SAI is a technique of SRM and can be deployed by an “injection of gas in the stratosphere, which then converts to aerosols. Injection of other particles is also considered” (IPCC, 2018, p. 348). According to this approach, SAI will be phased out gradually, and more time will be obtained for mitigation and adaptation (Ott, 2018). However, strings attached to SAI’s deployment are that SAI’s use should be conditional with a peak-shaving clause, substantial research on SAI’s side effects, and a well-defined termination plan (Ott, 2018). The peak-shaving approach is criticized because it will increase the climate debt of current generations and borrow temperature from future generations (Asayama & Hulme, 2019). The collective deployment of CDR, SRM, adaptation, and mitigation is also known as portfolio response to climate change. “As part of a ‘portfolio’ response to climate change, the idea is that solar geoengineering is gradually ramped up over some decades and then gradually phased out again after economies have decarbonized and carbon removal technologies have been developed to lower GHG concentrations” (Sapinski et al., 2021, p.7). To decrease global temperatures, there is a need to combine both CDR (long-term solution) and SRM (short-term solution) (Sapinski et al., 2021).

Moreover, it is crucial to consider the potential impacts of CDR and SRM on a country's governance and legal structures. These scientific techniques can significantly impact society’s social, political, and economic conditions (Honegger et al., 2018; IPCC, 2018). When designing policies concerning CDR and SRM, many countries would likely address them through a singular administrative unit. The exact impact of CDR and SRM on sustainable development depends on the region, climate-related challenges, and a country’s capacity to deal with these challenges (Honegger et al., 2018; IPCC, 2018). Large-scale CDR can have human rights issues and political implications, leading to political tensions and demands for governance reforms in the local area (Honegger et al., 2018; Burns, 2016; Craik, 2017). These potential impacts underscore the need for a comprehensive approach to climate interventions, considering their scientific and technical aspects and broader societal implications.

However, the opponents argue that a separate discussion of CDR and SRM can bring more clarity regarding the governance challenges of each approach, as each approach raises different governance challenges (Craik & Burns, 2016; Haraguchi et al., 2015). CDR is comparable to mitigation, while SRM is closer to adaptation (Marshall, 2017). SRM is potentially less expensive, and a single or few actors

can deploy SRM to impact the global climate system. At the same time, CDR needs the involvement of many actors (to have a global impact), and it is likely to be costly to have a global impact (Marshall, 2017). The risks and governance associated with CGE are very context dependent. Generalizing whether CDR or SRM benefits or harms a state is difficult because CGE will intersect differently with different states. Therefore, it is vital to consider the global South's perspectives and how these approaches may affect interests. These considerations may need to be considered on multiple scales: regional, state, sub-state, and local.

These interventions about developing states raise unique issues for the global South, meaning we think about a framework that better accounts for these issues. The key here is identifying the specific concerns of each type of intervention. For CDR, the main concerns relate to sustainability impacts like land use, water, and cost; but distributive issues around developed states using developing states to remove carbon. CDR provides an opportunity for development through credit payment, but there are risks that a form of climate colonialism may emerge. For SRM, concerns are more related to general risk, security issues, lack of control, and termination. I will discuss the existing literature and debates on the global South and CGE.

Boundary Drawing

A clear distinction between CDR and SRM has been observed in the last few years, and earlier “geoengineering” was the key term for referring to large-scale climate interventions, whether CDR or SRM (Buck, 2012; Humphrey, 2011). IPCC (2018) has reviewed CDR and SRM as potential approaches for attaining the targets set in the Paris Agreement, and it has concluded that both approaches should be considered seriously in the current situation. However, the IPCC has indicated more concerns about feasibility of SRM as a climate policy option (IPCC, 2023). In addition, the IPCC (2018) maintains that limiting the increase in temperature and reducing carbon emissions are interlinked, and both are urgent matters and require immediate action. As both CDR and SRM have implications for sustainable development (Honegger et al., 2018), it is prudent to look at them collectively, sometimes for attaining development in a country. A significant difference is that CDR would be preferable to SRM because it is more specific to helping the climate system regain its natural state (The Royal Society, 2009). Therefore, Bodansky (2012, p.4) argues that a delicate balance is needed in the research and governance of CDR and SRM to avoid excess or scarcity of any activity.

I have tried to maintain this distinction in my dissertation by discussing CDR in Chapter 3, targeted geoengineering, and SRM in Chapter 4. However, in Chapter 2, I will use the term CGE to collectively analyze the capability approach for large-scale climatic intervention, whether CDR, SRM, or targeted geoengineering. I think some issues concerning research or governance of CDR and SRM can be approached from a single conceptual lens. These issues are transparency, accountability, capacity, finances, and consent, which are common for all CGE approaches, although the context may vary. It is like treating different climate engineering technologies under a responsible research and innovation framework (Low & Buck, 2020). In addition, new technologies besides CDR and SRM may emerge for climate intervention under the realm of CGE. Adaptation and mitigation are not the focus of this project because scholars concerning these climate policy options have made a significant contribution. However, little literature concerning CGE and the global South is available, especially for South Asia.

The proponents of SRM research acknowledge strong opposition to expanding SRM research, but the probable benefits of further research on SRM outweigh the negative impacts of outright rejection (Parson et al., 2024; Winsberg, 2021). SRM has never been tried; any prediction about its potential success or failure can only be ascertained through more research. Most SRM work is based on computer models and analogs, and further research can bring more clarity to an uncertain situation (Kravitz & Macmartin, 2020, p. 64). In this scenario, when CGE approaches are experiencing divided support from certain academic and policy circles in the global North, it is crucial to understand the viewpoint of populous regions like South Asia regarding CGE (Rahman et al., 2018).

Overall, CGE research has recently gained new momentum as some research and policy initiatives have been announced in various countries. For example, Cambridge University announced the opening of a "Centre for Climate Repair" as part of the university's Carbon Neutral Futures Initiative (CCR, 2024). Regarding CDR, there is broader support from the public and private sectors. Biden administration has launched a \$3.5 billion program to capture carbon dioxide from the air. Under this program, large-scale regional CO₂ removal hubs will be established. The United Kingdom has initiated some steps to review governance and challenges associated with CDR (Lezaun et al., 2021). In the private sector, through XPRIZE carbon removal, Elon Musk has announced a series of activities and incentives for innovators and researchers to develop carbon removal solutions. However, how these innovative, risky, and expensive technologies will make their way into developing countries facing the adverse impact of climate change is yet to be seen.

The reason South Asia has been selected as a case study is because of specific reasons. First, this region is home to more than 2 billion people (if China is included), making it the most populated region in the world. Second, this region is one of the most vulnerable regions because of climate change and has been consistently ranked higher than many other regions by international experts and research organizations (World Bank, 2022). Third, China's proximity to South Asia and extensive economic engagement in the region under the BRI makes South Asia a viable study for exploring the link between CGE and development. Finally, the unique geopolitical dimension of the region and the hostile relations of three neighboring armed states, namely India, China, and Pakistan, make it a suitable case study for analyzing CGE, which has geopolitical and security implications. The hostile relationship between India and China can significantly reduce the impact of BRI in South Asia. At the same time, cooperation about glacier protection can increase regional cooperation and become a support for other developing countries of the region.

CGE and the Global South

In this section, I will discuss the peculiar nature of CGE governance and special considerations of the global South concerning climate policy options and development aspirations. CGE potentially further increases the existing patterns of inequality at the global level (Carr & Preston, 2017, p.773). CGE, like many other international relations issues, has a north-south aspect encompassing “Northern responsibility, Southern victimhood” (Horton et al., 2015, p.244). There are apprehensions that powerful countries, private actors or multilateral institutions could easily manage the marginalized countries or even frighten them regarding CGE governance (Leal-Arcas & Filis-Yelaghotis, 2012; Smith, 2018; Olson, 2011). For example, trade sanctions can restrict any unilateral advancement of some developing states toward CGE research (Leal-Arcas & Filis-Yelaghotis, 2012). Developing countries could also be over-cautious about the developed countries’ hegemonic designs and ability to control and exploit the world’s climatic conditions (Leahy, 2010). The lack of engagement of the global South in scholarly and policy debates would create a situation in which developing and developed countries do not deliberate about the research and governance of CGE.

CDR and SRM require a high degree of technical, economic (more for CDR) and governance capacity, but developing countries lack these areas. Regarding distribution, CDR debates have focused on which states shall provide CDR and how CDR will occur (Poza et al., 2020). The distribution of CDR has conflicting pressures as developing might like to participate in CDR schemes as these schemes can

generate revenue for them (like REDD+). However, the requisite capacity is not available to the policymakers and scientists of developing countries. In addition, large CDR schemes may open an avenue of exploitation in which developed countries benefit by successfully offsetting their carbon emissions. However, developing countries fall short of their emission reduction targets. Global South would need to divert resources to CDR but may not benefit from removals as transferred to the financing country. The equitable CDR deployment depends on questions of who is benefiting and who is financing CDR schemes that can lead to the acceptable design of these schemes. For example, a CDR initiative under BRI and executed in a developing country could have different implications than a CDR scheme sponsored by the USA in the global South. The moral hazard argument rephrased through the idea of mitigation deterrence also suggests that CDR may be a preferred method for stakeholders. However, it may not benefit the ecosystem because CDR's net gains are less than mitigation (Carton et al., 2023). Then, the nexus between development between CDR and SRM is less explored, which has resulted in less active participation of the global South in CGE debates.

The global South has shown limited participation in research and policy debates regarding CGE (Biermann & Möller, 2019; Nassiry et al., 2017; Winickoff et al., 2015). Even though recent research suggests that scholars and policymakers cannot make assumptions about attitudes respecting SRM in the global South (or anywhere) and likely cannot essentialize those attitudes (Sugiyama et al., 2020). Very few initiatives and institutions in developing countries are engaged in CGE research. The Solar Radiation Management Governance Initiative (SRMGI) is one such initiative that promotes the scientific and governance understanding of SRM in the global South with local stakeholders' partnerships. SRMGI has established a decimal fund for researchers from the global South regarding SRM research (The Degrees Initiative, 2024). There are many reasons why developing countries should explore CGE research along with adaptation and mitigation policies.

Climate change is an existential and immediate threat for some developing countries. Through SRM, developing countries can buy more time, avoid the immediate impacts of climate change, and generate the required finances for adaptation measures (Svoboda, 2016). SRM might play an influential role when deployed, along with mitigation and adaptation measures (Macmartin et al., 2018). Tactical deployment of adaptation, mitigation, and CGE to avoid immediate implications of climate change is a possible option for some developing countries. SAI may be cost-effective compared to other climate responses for a short period (IPCC, 2018). Developing countries lacking

technical and financial capacity may be more interested in options like SAI (in the short term) than doing nothing.

Furthermore, the global South can be a potential partner of the global North in implementing the CDR in the form of CDR projects and activities and earning much-needed foreign investment. CDR technology consistent with 2°C requires a substantial financial resource (Craik & Burns, 2016), which is not readily available in many developing countries. Developed countries' financial collaboration with developing countries is essential to promoting climate-related technologies (Rahman et al., 2018). In some cases, developing countries have offered land for climate change control initiatives, while developed countries have contributed through their financial and technical resources (Daharwal et al., 2023). This phenomenon is evident in the clean development mechanism (CDM), in which developed countries implemented emission reduction projects in developing countries. There is a possibility that developed countries may divert their climate finances from mitigation to CDR projects under Article 9 of the Paris Agreement (Craik & Burns, 2016). These North-South financial partnerships can create options like debt for nature swaps. There are indications that some developing countries might be looking to debt for nature swap policy with donors from developed countries in exchange for their efforts related to afforestation and reforestation (Ritchie & Mangi, 2021). With notable transnational economic and trade presence, even big economies like China may consider nature debt-for-nature swap deals for debt servicing purposes with host countries of the BRI (Yue & Wang, 2021). One of the characteristics of BRI relations is that host countries increase their indebtedness towards China. China may view climate services, such as CDR, as a potential way to address debt default. If this is true, the approach might be quite hegemonic as China has high leverage and could potentially exact a high cost at the expense of local communities. Article 6 of the Paris Agreement allows the countries to voluntarily cooperate and attain emission reduction targets set in their NDCs. However, one possible concern regarding CDR sinks could be the exploitation and use of the global South as a colony for carbon sinks while securing key benefits for the global North over the long term.

Even if there is less viability of the CGE as a climate policy option, the technical and ethical aspect of CGE governance still needs to be addressed. It deserves the active participation of developing countries in the CGE debates. Many social and cultural issues related to emerging technologies are settled at the engineering and design stage (Oosterlaken, 2012). On the governance side, due to the large-scale deployment and implications of CGE, developing countries cannot be immune to the impacts of CGE, especially SRM, even if they do not actively join or deploy these technologies. For

example, developing countries may receive impacts of techniques like SAI's large-scale deployment (Nassiry et al., 2017). An "arctic injection (that) would cool the atmosphere down to latitude 30°N, weakening the summer monsoon over Africa and Asia and reducing precipitation, just like tropical injections of stratospheric aerosols" (Robock et al., 2010). SRM may have unequal effectiveness in various regions (Moreno-Cruz et al., 2011), and these consequences could exacerbate governance challenges for developing countries even if developing countries have lesser engagement and expertise with CGE debates (Nassiry et al., 2017). Besides these technical issues, some ethical concerns associated with CGE governance also demand the active engagement of the global South. Some ethical concerns associated with CGE research are intergenerational application, financing of these projects, compensation for negative harms, and procedural and distributional justice.

The mitigation deterrence scenario is one prominent ethical concern of CGE governance. The moral hazard is a situation that may discourage countries from mitigation and adaptation efforts because CGE provides an easy and less expensive alternative to tackle climate change-related issues than adaptation and mitigation (The Royal Society, 2009, p. 45, NAP, 2015(b)). Cairns (2014) describes this irreversibility of SRM as path-dependency or socio-technical lock-in. Lock-in or path dependency is about investing in an approach that turns out to be sub-optimal but, due to investment, does not deviate from the course, perhaps because of systemic infrastructure investments or other decisions around climate. The acceptance of SRM might delay mitigation, but delaying mitigation makes using SRM inevitable. The key is that the result might reduce a state's overall agency and choice, which is key for Sen as the capabilities approach is about keeping options open to allow an informed choice to increase capabilities and functions.

Some countries may start making policies that support fossil fuels while knowing they can maneuver the global environment according to their desires through CGE. CGE's ethical issues may be more challenging than technical and scientific ones (Preston, 2016). CGE needs further ethical evaluation, especially from a developing country's perspective, because developing countries have much to lose if things go wrong in case a superpower unilaterally deploys CGE. The ethical aspect of any global regime is vital for the north-south relationship because the structural phenomena of unequal development between developing and developed countries exist (Blomfield, 2015). If developing countries are subject to the adverse impacts of CGE even without participating in its deployment, joining CGE's research and governance debates to influence and design them may be necessary. This way, developing countries can understand the intricacies of CGE and advocate for fair and beneficial

approaches to their interests. Developing countries may also like to influence CDR accounting, financing, and human rights safeguards, especially in weak democracies. There is a need to recenter CGE research to increase engagement of developing countries by applying different theoretical lenses.

It is challenging for developing countries with limited financial and technical resources to incorporate a low-carbon strategy while meeting their energy and infrastructure demands and managing immediate threats like floods, droughts, heat waves, and the rapid melting of glaciers. The case of recent floodings in Pakistan suggests that the capabilities and development plans of the global South are at significant risk because of climate change. Small Island Developing States (SIDS) and Least Developing Countries (LDCs) are facing existential risks because of climate change (IPCC, 2018). An organization, the German watch, based in Berlin, has developed a global climate risk index to measure the impact of climate change in different countries. It observed that among "the ten most affected countries and territories (1998–2017), eight were developing countries in the low-income or lower-middle-income country group" (Eckstein et al., 2018, p.3). The statement highlights that low-income and lower-middle-income countries are disproportionately affected by climate change impacts. Despite contributing less to global emissions, they face greater vulnerability and fewer resources for adaptation. This emphasizes the need for climate justice and global support for these nations.

Disengagement of Global South in Climate Geoengineering Scholarship

The participation of the Global South in research and experimentation related to climate geoengineering is not only an issue of equity but also a critical necessity. This serves as a call to action that many scholars have highlighted, underscoring the importance of addressing this gap to promote a more balanced and comprehensive dialogue (Winickoff et al., 2015). Notably, two exceptions from the global South—India and China—have taken center stage. Researchers and policymakers in these countries have shown a strong interest in climate geoengineering and its implications for their unique climate challenges and policy responses (Bhowmick et al., 2021; Cao et al., 2015). In my research on the Web of Science database, I investigated the involvement of scholars from the global South in CGE. I focused on ten specific research areas related to social sciences within this literature, identifying the primary country associated with each publication. This targeted search yielded 357 relevant publications, providing insight into global South engagement in climate geoengineering research.

I began with a literature search using the Web of Science, concentrating on publications in CGE; analyzing the publication tree map and line chart data offered valuable insights into regional publication trends and enabled me to focus on scholars' participation by country. By examining author affiliations and institutional locations, I could identify scholars from regions in the global South and categorize the publications according to the primary country associated with each author's institution.



Figure 1: Climate Geoengineering Publications by Research Area

The treemap illustrating CGE Publications by research area offers a clear overview of the prevalent fields within CGE scholarship. The size of each box represents the number of publications in each area, providing a visual representation of research emphasis. The largest segment of the treemap is dedicated to Environmental Studies, boasting a publication count of 241. This field likely includes research on ecological impact assessments, climate modeling, and environmental risk analyses—crucial elements for understanding the potential effects of geoengineering on natural systems. The prominence of this field indicates that geoengineering is primarily examined through an environmental lens, emphasizing ecological feasibility and impacts.

Political Science, International Relations, and Law are prominently featured in the treemap, highlighting the complexities governing geoengineering technologies. These disciplines are vital in shaping discussions around governance frameworks, international collaboration, and legal regulations. This emphasis reflects a growing acknowledgment of geoengineering as a global challenge necessitating robust and multilateral governance structures. However, the conversation

remains largely dominated by institutions in developed countries, where legal and political frameworks for climate governance are more established. This situation highlights the urgent need for a more inclusive and globally representative approach to governance discussions.

Research areas that address specific regional vulnerabilities, such as Geography and Urban Planning, occupy relatively smaller sections of the treemap. This suggests that geoengineering research has predominantly been framed from broad, global perspectives, potentially neglecting the localized climate challenges developing nations face. With 24 publications in Geography and 19 in Urban Planning, these disciplines could provide valuable insights into the regional impacts of geoengineering, particularly for countries in the global South. Yet, their representation in this discourse needs to be improved.

Furthermore, smaller fields like ethics (with 21 publications) and Social Sciences indicate an increasing concern for the societal implications of geoengineering. These fields explore critical issues related to social justice, intergenerational equity, and the moral responsibilities associated with climate intervention technologies. As ethical debates expand, there is a pressing need for diverse perspectives, particularly from developing countries, where social equity issues are often at the forefront of climate impacts. Based on the data in the tree chart, I created a line chart.

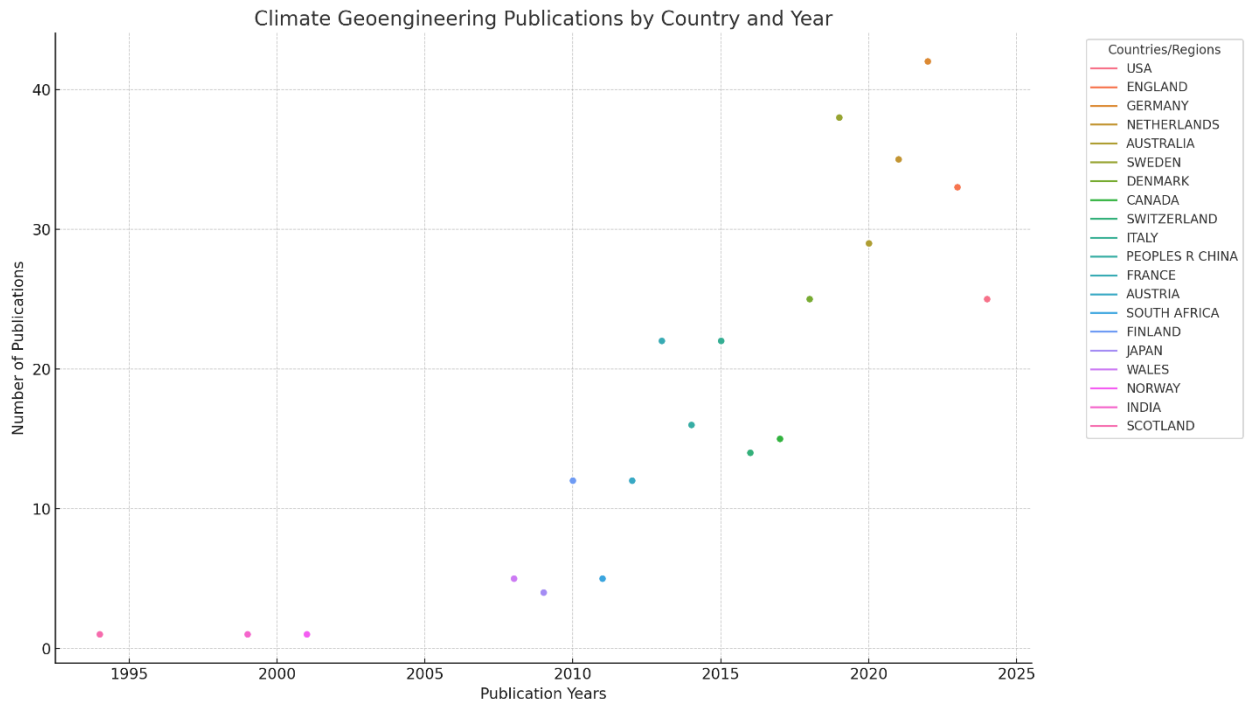


Figure 2: Climate Geoengineering Publications by Country and Year

The line chart illustrates distinct trends in research of CGE output among various countries over time. Each line corresponds to a specific country, with the y-axis indicating the number of publications and the x-axis representing the years. Countries such as the USA, England, Germany, and other developed nations show significant research contributions, consistently increasing their publication counts, particularly over the past decade. This trend underscores their strong academic and financial commitment to geoengineering research. Notably, the USA has the highest number of publications, reflecting its extensive investment in environmental science and technology. In contrast, developing nations like India and South Africa appear infrequently in the publication data, showing only a few entries on the chart. Their sporadic involvement, with no significant upward trend, suggests limited participation from the global South, potentially due to financial constraints, inadequate access to research infrastructure, or differing national priorities. Among developing countries, China (noted as "Peoples R China") is noteworthy for its substantial increase in publications in recent years. This trend signifies China's escalating research capacity and interest in climate technologies, suggesting a potential transformation in the geoengineering research landscape. Notably, some economically advanced developing countries are becoming more active participants in global scientific discussions, including those surrounding geoengineering.

The accompanying chart illustrates a rising publication trend from the early 2000s to 2024 across various participating countries. This upward trajectory reflects a growing global awareness and scholarly interest in climate geoengineering, likely spurred by the pressing need for climate change mitigation. However, the concentration of research in developed nations highlights a critical need for more inclusive participation from developing countries, particularly given their heightened vulnerability to the impacts of climate change. The data points to a marked deficit in participation among developing countries in climate geoengineering research. Several factors contribute to this gap. Engaging in high-level research on climate geoengineering typically necessitates substantial funding, advanced technologies, and specialized expertise. For India and South Africa, financial limitations and constrained research infrastructure may impede their full engagement in this domain, in stark contrast to China, which has significantly bolstered its scientific research infrastructure over the past decade.

In contrast to developed countries with established research institutions and robust funding bodies, developing nations often lack the necessary infrastructure dedicated to climate research. China has made considerable strides in developing research capabilities. At the same time, India and South

Africa may grapple with structural barriers that restrict their participation in geoengineering initiatives, which demand both high technical proficiency and significant financial investment. Given their immediate vulnerabilities to climate change, developing countries frequently prioritize adaptation strategies over mitigation or interventionist measures like geoengineering. For India and South Africa, the focus on resilience-building initiatives may overshadow investments in geoengineering research, often seen as uncertain or high-risk. Conversely, China appears to balance adaptation and geoengineering, reflecting its economic capacity and climate priorities.

The predominance of developed countries in CGE research raises imperative questions about inclusivity within global climate science governance. An absence of substantial contributions from the global South suggests that geoengineering technologies' development and potential implementation may overlook equitable considerations for the most vulnerable populations who endure unintended consequences. Furthermore, the comparatively lower participation of India, China, and South Africa in governance-related research underscores the need for their perspectives to be adequately represented in the formulation of global geoengineering policies.

The line chart and treemap illustrate the stark disparity in CGE research participation between developed and developing countries. Developed nations dominate the quantity and diversity of research fields, whereas countries like India, China, and South Africa exhibit varied levels of engagement. China demonstrates an increasing trend in research participation, while India and South Africa remain significantly underrepresented. Addressing the barriers that impede participation from developing nations and promoting international collaboration incorporating their perspectives and needs are essential to fostering a more inclusive approach to climate geoengineering. Encouraging partnerships, enhancing capacity building, and establishing funding mechanisms are vital to bridging this gap and facilitating a globally representative dialogue on climate geoengineering.

Furthermore, reviewing prominent climate and CGE forums, including the IPCC reports COP sessions. Developing country's representation and participation in forums like the IPCC has remained low, highlighting issues of the legitimacy of the policymaking process (Beck & Mahony, 2018). It can help assess the leadership dynamics in CGE discussions, particularly regarding global South engagement. As the principal scientific authority on climate change, the IPCC has traditionally been led by researchers and institutions from the global North (Ho-Lem et al., 2011). An analysis of IPCC assessment reports on CGE may reveal the primary contributors and focal research areas. If a significant proportion of lead authors and cited studies originate from the global North, this could

indicate limited global South engagement in shaping the narrative and policy recommendations. COP sessions provide a platform for international climate-issue negotiations, encompassing discussions on emerging topics like CGE. By observing which countries take the initiative to introduce or endorse CGE-related agendas, one can ascertain whether global North countries predominantly drive the dialogue. A scenario where developing nations primarily react to these discussions rather than actively set the agenda may reflect a more passive engagement from the global South. If key contributors and collaborations predominantly involve Northern countries or institutions, this would further underscore the imbalance in global South engagement.

The treemap and line chart data confirmed limited representation from the global South regions, showing that most CGE publications come from Europe and North America. Furthermore, while global North countries demonstrate increasing participation, the global South representation still needs to be improved, particularly in the field of SRM, as noted with the Geoengineering Monitor map.³ I considered the Geoengineering Monitor map a potential source in refining the dataset and interpreting the CGE publication trends. By filtering for SRM, the map reveals virtually no active global South engagement, underscoring the disparity in research presence. Filtering for only SRM or adding Greenhouse Gas Removal (GGR) on this map also supports the trend of global South underrepresentation, revealing that active CGE projects and research are overwhelmingly concentrated in Europe and North America. This observation aligns with the dataset and visualizations derived from the tree map and line chart, reinforcing the conclusion that global South scholars are underrepresented in research output and field activity within CGE. Regarding markers beyond publication, another challenge in global South involvement relates to field research availability. Only some field studies on CGE are conducted in these regions. This further limits global South contributions and influences mainly theoretical or secondary analyses, creating a barrier to substantive engagement in the field.

Theoretical Approach

In this dissertation, I have drawn on Amartya Sen's capability theory to analyze CGE's application in South Asia. The capability approach is the subject of growing scholarly attention, and besides Amartya Sen, other scholars have enriched the capability framework. Sen has acknowledged the contributions

³ [Geoengineering Map](#)

made by Martha Nussbaum, Sabina Alkire, Enrica Chiappero-Martinetti, Flavio Comim, David A. Crocker, Reiko Gotoh, Mozaffar Qizilbash, Jennifer Prah Ruger, Ingrid Robeyns, Tania Burchardt and Polly Vizard (Sen, 2009, pp,234-235). The rationale behind choosing Sen's capability approach as the framework is that it brings together the ideas of development and justice, which are necessary for analyzing CGE's role as a climate policy option in developing countries. The capability approach can enable scholars to explore CGE from the development and climate justice aspects. At the heart of Sen's approach, development should focus on improving real capabilities allowing humans to live a valued life. Because climate change dramatically reduces those capabilities, CGE may be understood as a just response to climate if it can be understood to reduce the effects of climate change on capabilities. In this sense, a stable environment is meta-capability because it enables individuals and groups to live meaningful lives across numerous forms of capability. (Holland, 2012). In Sen's words,

Development can be seen, it is argued here, as a process of expanding the real freedoms that people enjoy. Focusing on human freedoms contrasts with narrower views of development, such as identifying development with the growth of gross national product, or with the rise in personal incomes, or with industrialization, or with technological advance, or with social modernization. Growth of GNP or of individual incomes can, of course, be very important as means to expanding the freedoms enjoyed by the members of the society. But freedoms depend also on other determinants, such as social and economic arrangements (Sen, 1999, p.3).

Sen believes there are various freedoms, i.e., political, social, economic, and environmental, and all these freedoms are interlinked and strengthen each other. In this way, strengthening the environmental freedoms of people through adaptation, mitigation, or CGE can also influence political and economic freedoms. By applying the capability framework to CGE governance, I do not see carbon removal or reduction of temperatures as the goal of CGE but instead as reducing the injustice caused by climate change. Scholars have explored some equity rationales for CGE research, especially from developing countries' perspectives (Rehman et al., 2018).

CGE is primarily a technology-based climate policy option. Sen's capability framework has analyzed various technological innovations in developing countries (Oosterlaken et al., 2012). Human capabilities are protected and enriched by social liberties and public facilities (Sen, 1999, pp.41-42). In the capability framework, technology is treated as a resource to provide facilities essential for nurturing human capabilities. Improvements in social arrangements create a favorable environment

for human uplift (Sen, 1999, p. 45). The peculiar social arrangements have influenced countries' social and economic trajectories. Sen draws a comparison between South-Asian and Southeast-Asian countries on this basis and identifies that an essential reason for the early development of Southeast Asian economies is the focus on these social arrangements.

One benefit of applying the capability framework for CGE research and governance is that Amartya Sen has already used this framework to address the complex issue of famine in developing countries. Problems like famine and climate change are wicked problems that cause human capability deprivation. Sen argued that famine is not just about food production or its reduction; it is an issue of agency that can be effectively managed by dealing with the related social and economic problems. Sen had seen people suffering around him from starvation and hunger when famine struck in Bengal in the 1940s. Those events have lasting impacts on Sen's work, and we may call the capability framework a product of human misery and deprivation:

We live in a world with widespread hunger and undernourishment and frequent famines. It is often assumed—if only implicitly—that we can do little to remedy these desperate situations. It is also presumed, frequently enough, that these maladies may actually get worse in the long run, especially with the growth of world population. Tacit pessimism often dominates international reactions to these miseries in the world today. This perceived lack of freedom to remedy hunger can itself lead to fatalism and the absence of serious attempts to remedy the miseries that we see (Sen, 1999, p.160).

Sen's argument about pessimism about hunger is relevant to the country's inability and fear of dealing with climate change issues, as climate pessimism and fatalism are also present. CGE can be seen as a response to climate fatalism. Sen argues that apparent causes like food production are not the only cause of problems like famine, as there are multiple and interlinked events. However, Sen argues against pessimism while dealing with issues like famine and believes in human ingenuity. Similarly, the capability framework for CGE governance provides hope for human ingenuity amid wicked problems like climate change. CGE, as a policy option, needs to be analyzed for human well-being, which is under threat due to anthropogenic climate change. CGE for human well-being and protection of capabilities threatened by climate change, preserving the glaciers, can reset the debate about the future of CGE research.

I am impartial about deploying SRM, but I favor further research regarding CGE to understand CGE application and governance, particularly concerning developing countries. I value the capability

approach because it treats knowledge as an essential social capability. Further research can show us what is harmful and beneficial. However, some places and scenarios in developing countries may not appear crucial for global climate change. However, these places are important for local people and their capabilities. Local or bottom-up decision-making is also important for the capability approach as the choice (agency) is central to Sen's idea of freedom. While future decisions may need to be made about global SRM, targeted approaches may retain a level of choice and allow for further exploration without being hegemonic. The governments and corporations that are supposed to reduce fossil fuel consumption and enhance their emission reduction efforts under the Paris Agreement should do so without recourse to GGE. However, a few scenarios and geographical locations may explore a multipronged climate response, including CGE. Any artificial intervention should be with limited impact and through the least controversial, widely accepted, and scientifically tested techniques.

Focusing on Sen's capability approach, this dissertation focuses less on some key debates regarding CGE. Some of these debates are related to CGE and the Paris Agreement, or CGE, as a climate policy option for developed countries. Moreover, debates like CGE and their potential implications for the temperature and energy situations are important. All the discussions on CGE are important, and they enrich the scholarship. However, I am better positioned to discuss CGE and developing countries by focusing on the capability approach.

Overview of the Capability Approach as Applied to CGE

The dissertation's central argument revolves around the capability approach's dual purpose. This approach reframes CGE as a developmental tool and establishes a justice-oriented framework for assessing CGE initiatives. By presenting the capability approach as a framework that goes beyond mere economic growth, emphasizing individual well-being, freedoms, and the broader implications of development as articulated by Sen—the dissertation lays the groundwork for its main argument. To begin, it is essential to reframe CGE as a development initiative by exploring Sen's definition of development. This dissertation grounds its approach in Sen's development concept as expanding individual freedoms and capabilities to enable people to lead meaningful lives. By presenting CGE as a developmental endeavor, this dissertation argues that CGE initiatives could align with Sen's vision by contributing to global well-being and climate stability, which, in turn, support the enhancement of individual and collective freedoms.

The dissertation subsequently examines CGE as a developmental tool. It contends that when aligned with a capability approach, CGE can be recognized as a means of development by contributing to climate stability and, in turn, facilitating broader socio-economic benefits. By tackling climate impacts that hinder social and economic progress, CGE has the potential to protect essential capabilities, providing a sense of security for the future. This reframing positions CGE as an environmental intervention and a vital element of sustainable development. Discussing CGE in theoretical terms while connecting these ideas to real-world implications establishes a foundational argument that prepares the reader for the practical evaluative frameworks that will follow.

The capability approach is crucial in establishing evaluative criteria for 'just CGE.' The initial step involves defining 'just development' specifically for CGE through the lens of the capability approach. This focus on the capability approach highlights its practical application and significant contribution to the objectives of the dissertation. To integrate CGE with the concept of "just development," the dissertation incorporates Sen's notion of justice, which encompasses principles of fairness, equality, and freedom. This framework suggests that CGE must not only address climate impacts but also do so in an equitable manner, particularly about vulnerable or marginalized populations. It clarifies that "just CGE" seeks to extend the values of the capability approach to CGE, ensuring that initiatives are fair and contribute to authentic development.

The subsequent focus is on developing evaluative criteria for CGE activities. This dissertation outlines specific criteria derived from the capability approach, which serves as a framework for assessing CGE's alignment with the principles of just development. This framework comprises three key elements. The first is equity, which evaluates the distribution of CGE's impacts across diverse populations, particularly safeguarding marginalized communities. The second element is freedom, which examines whether CGE empowers individuals or inadvertently creates new dependencies that could restrict their autonomy. The third element is sustainability, ensuring that CGE initiatives promote long-term ecological balance while aligning with well-being objectives. These criteria establish a structured basis for evaluating CGE initiatives, providing a normative foundation aligning CGE with the principles of just development. This approach strengthens the theoretical argument and serves as a link to the dissertation's methodological section.

The case studies presented later in the dissertation apply these criteria to real-world CGE initiatives. Through these case studies, the dissertation illustrates the practical applicability of the capability approach in assessing the justice and developmental impact of CGE. This empirical approach anchors

the theoretical aspects of the capability approach in specific examples, demonstrating its relevance to contemporary CGE practices and frameworks. The dissertation emphasizes that the capability approach framework provides an evaluative and normative foundation for CGE. By articulating this dual purpose—reconceptualizing CGE as a developmental intervention and evaluating it from a justice-oriented perspective—the dissertation fortifies its argument for CGE as a manifestation of just development. This structure harmonizes the values of the capability approach with the objectives of the dissertation, highlighting how CGE initiatives can advance broader human and ecological goals through an integrated, justice-based framework.

Methodological Approach and Data Analysis

Drawing on Sen's capabilities approach, I developed a theoretical approach that better captures CGE's important aspects to developing countries, and then I applied that framework through two case studies. The purpose of the case studies is to assess the value of the framework but also to examine the specific development structures and challenges potentially associated with CGE from a justice perspective. I used a mixed-method qualitative approach in this dissertation. In the second chapter, I rely on Amartya Sen's capability approach to explain an alternate theoretical framework for analyzing the CGE research and governance from an equity perspective. In the third chapter, I develop a case study approach to examine the role of CDR as a climate policy option for a developing country like Pakistan under the BRI. In the fourth chapter, I use South Asia as a case study to analyze the possibility of targeted geoengineering for glacier preservation in the Himalayas, Karakoram, and Hindu Kush (HKHK) region. My experience with climate change and being from a developing country has inspired my case study approach. Climate change is an urgent issue, and there are reservations about the adequacy of existing efforts to deliver the necessary results in mitigating the impacts of climate change. In this scenario, interventions like CGE deserve more debate to ascertain their relevance and reliability for future courses of action. I have worked in a developing country (Pakistan) in the field of climate change, and I can understand how deeply and urgently climate change is hurting developing countries' economic and social structures. One of the key things I noted during my academic and professional career is that developing countries have a significantly different point of view about climate change issues than developed countries regarding causes, implications and solutions.

I collected data from multiple sources, mainly secondary literature and primary documents. A select number of semi-structured interviews of experts with relevant knowledge of the case study subject

matter supplements these sources. Semi-structured interviews are an important component of qualitative research through which researchers access exclusive information based on the participants' life experiences and work (Kakilla, 2021). In the case of this dissertation, the knowledge of informants is a crucial source of knowledge because there may be some developments in South Asia about CGE that are not in the public domain. For Chapter 2, my data consisted of a literature review and critical analysis of existing theoretical frameworks for CGE research and governance. This literature comprises insights from various fields like development, science, philosophy, law, and global environmental governance. For Chapter 3, I combined literature and semi-structured interviews with experts on CDR, BRI, and the climate policy of Pakistan. For Chapter 4, I relied on a literature review and semi-structured interviews with experts on South Asia, SRM, and glacier preservation. The semi-structured interviews helped me to structure my third and fourth chapters in a policy-relevant way for CGE in South Asia. I attended a few online events and an in-person summer school on geoengineering in Banff, Alberta, Canada, in 2019. For identifying interviewees, I used the key informant approach and snowball approach. Snowball is an approach in which currently enrolled participants of a study help to identify and recruit future subjects for the study (Simkus, 2023). The interviews were semi-structured, and all interviewees had some basic questions. For the analyses of interview transcripts and to identify primary themes in Chapter 3 and Chapter 4, I used the qualitative data analysis software NVivo, which I used to code and systematically explore relationships among individual data through thematic analysis.

Part of my motivation for looking at the BRI is that I am interested in developing the idea of CGE as a form of Senian-inspired development. As the most prominent vehicle for improving development outcomes in Pakistan, the BRI provides an opportunity to explore this theme of an ongoing multi-national development structure. BRI is the Chinese-sponsored transnational development initiative and is the most consequential development initiative. The chapter intends to explore whether the BRI could provide meaningful governance, which includes normative direction, capacity, finance, and oversight for CDR in South Asia (Pakistan). BRI profoundly impacts development patterns and climate situations in the host countries, mainly developing nations. BRI provides a south-south dimension that may be important as this matches emerging views of development as a global phenomenon and may align with some of Amartya Sen's ideals on autonomy.

China and host countries of the BRI could explore CDR options for attaining emission reduction goals under the Paris Agreement. However, it is also important to note whether partnering with developing

countries of the BRI could rely on China or not for research and deployment of CDR. Existing CGE literature focuses only on China's domestic GHG emissions and strategic interests. China is one of the largest GHG emitters globally, and its emissions continue to rise. Nevertheless, with the inclusion of the BRI, China's development path is undermining global emission reduction goals envisioned under the Paris Agreement because the BRI is pushing the world toward a carbon lock-in (Ivleva, 2021, p. 24, Lew et al., 2021; Carey & Ladislaw, 2021). Some developing countries in South Asia, like Pakistan, Sri Lanka, and Bangladesh, have received significant Chinese investment under the BRI in the last few years. This Chinese investment includes coal-fired power plants, which are a source of carbon emissions and are inconsistent with the emission reduction commitment under the Paris Agreement.

Whether CDR would become a climate policy option under the BRI for a host country is hard to predict without considering the specific aspects of a country's involvement in the BRI. An issue with BRI-type projects is that they are diverse; therefore, the characteristics of the BRI and subsequent greening partnerships depend upon the geographical and bilateral context of China and the host country (Ivleva, 2021). There is no official list of the Belt and Road Countries (B&RCs) as BRI continuously evolves. The BRI's total number of host countries is around 126, and these numbers are based on the bilateral Memorandum of Understandings (MOUs) between China and B&RCs (Jun, 2020). Therefore, to have a focused view, I have chosen the case of Pakistan to discuss the Chinese partnership with Pakistan and possible scenarios for CDR research and deployment. Pakistan's case study of CDR as a climate policy option under the BRI can be beneficial for examining similar cases for other countries under the BRI. A brief background of Pakistan's economic and energy position would help understand the nature of China's partnership with Pakistan. Four informants were interviewed for this study. The first informant is a researcher who contributes to South Asia's climate change and climate policy issues and has a broader understanding of CDR. Second, the informant is a former diplomat who represented Pakistan in climate change negotiations for many years. The third informant is a researcher whose area of expertise is China and the BRI, and he writes about BRI's climate change impacts and China's low-carbon development. Fourth, the informant is a climate policy expert who has worked for the government of Pakistan and has represented the government of Pakistan in many international agreements and conventions on environment and climate change. To protect the interviewees' identity, I refer to them as A, B, C, and D when quoting them verbatim. The interviews took place between 2021 and 2022, and each interviewee was interviewed through Zoom (online) for approximately 60 minutes, depending upon the availability of each interviewee. These were semi-structured interviews, and interviewees were free to make additional comments and observations

during the interview. All interviews were audio recorded on Zoom. The select nature of the interviews was meant to provide further insights and perspectives that were not readily apparent from reviewing literature and primary documents. My research is primarily qualitative, and fewer interviews in qualitative research are acceptable when the primary purpose of the interviews is to seek publicly unavailable information. The number of interviews in a research project is an important factor. “The answer to ‘how many qualitative interviews is enough’ is ‘it depends’ (Baker et al., 2018). Qualitative research has fewer interviews than quantitative research, as qualitative research aims to seek in-depth information from a few individuals (Baker et al., 2018).

For Chapter 4, I investigated the potential role of targeted geoengineering as a climate policy option to address issues like melting glaciers in the HKHK region. Data sources of this study included an extensive literature review, analysis of primary documents, and semi-structured interviews with experts on CGE, climate change, glaciology, and climate policy. The literature reviewed includes the capability approach, climate policy, glacier protection, and CGE. Primary documents include NDCs from South Asian countries, international treaty documents, and the charters of some regional organizations. Five informants were interviewed for this study. Three informants have regularly contributed to CGE scholarship relevant to developing countries, while two have worked with a regional organization with expertise in glaciology and climate change. One informant is a well-known climate policy expert representing his country in international negotiations at UNFCCC and was part of a working group in IPCC. To protect the interviewees' identity, I refer to them as M, N, O, P, Q, and R when quoting them verbatim. The interviews took place between 2021 and 2022, and each interviewee was interviewed through Zoom (online) for approximately 60 minutes, depending upon the availability of each interviewee. These were semi-structured interviews, and interviewees were free to make additional comments and observations during the interview. All interviews were audio recorded on Zoom.

I acknowledge several shortcomings in my methodology. Regarding the interviews, the number of participants is small because there are limited experts with combined knowledge of CGE and South Asia. As discussed earlier, many scholars have highlighted the limited participation of scholars from the global South in CGE debates. In addition to that, during the COVID-19 pandemic, there were travel restrictions, and there was no opportunity to have in-person interviews with experts. Some interviewees could not manage to have interviews despite their initial acceptance of my interview request because of their personal, professional, and health issues during the COVID-19 pandemic. A

significant drawback of restrictions on traveling during the COVID-19 pandemic resulted in my inability to attend key conferences related to my research work and missed participant observation, an essential tool for evidence corroboration. I stopped collecting data in June 2023, so this dissertation may not have all the latest publications on CGE.

Expected Contributions

This study makes a theoretical and empirical contribution to the field of CGE. The interdisciplinary project combines knowledge from the capability approach, CGE, South Asia, climate change, global governance, science, culture, international environmental law, and development studies. The project's key objective is to explore the idea of CGE as a development. This is important because of the current lack of engagement by the global South in CGE debates, which are often framed as either solving a problem that the global South believes it is not responsible for or framing CGE as a paternalistic response to addressing southern victimhood. My study also provides a justice-oriented approach to CGE research and governance that focuses on enhancing capabilities, retaining agencies, and concentrating on the capabilities of people in the global south.

The study also contributes through CDR and targeted geoengineering studies from a South Asian perspective. It is especially relevant to applying the capability approach to CGE governance and issues like capacity, liability, financing, and decision-making in the context of developing countries. Concerning empirical contribution, this project addresses the concerns that scholars and policymakers from the global South have marginal representation in CGE research and governance debates. Several scholars from the global South have been interviewed during this project, and quite diverse views regarding CGE's future in developing countries have become part of this study.

This project also explores the links between the values of South-Asian society and their relationship with scientific innovations like CGE. Any branch of science cannot be immune to societal and cultural activities. Science Technology and Society (STS) scholarship offers a unique opportunity to understand and imagine how policies, science, and society can influence each other (Jasanoff, 2016). Responsible innovation is vital when discussing the governance of CGE concerning the global South, as developing countries' unique values and norms could be a decisive factor in promoting or disowning CGE research in the global South. My dissertation has policy relevance, especially for South Asian countries, as countries like Pakistan and Bangladesh are considered the most vulnerable due to climate change. These vulnerable countries fulfill international emission reduction targets and become immune from

the impacts of anthropogenic climate change. In this situation, South-Asian countries would like to analyze all possible options, including CGE, to help them effectively respond to climate change.

The customization of targeted geoengineering and the ability to develop more regional interventions can play an important role in the acceptance of CGE as a research and policy climate policy option. Targeted geoengineering, unlike global-scale interventions, aims at regional or local interventions. In a few articles, scholars like Moore (2020) and Bodansky & Hunt (2020) have explored the option of targeted geoengineering regarding the Arctic. These articles have highlighted that global SRM may have become too controversial, and it is time to explore regional or targeted geoengineering options, which might vary from region to region. These articles have inspired me to explore targeted engineering regarding glacier preservation in the HKHK glaciers. Targeted interventions in the HKHK region for glacier protection, conservation, and advancement are novel but important ideas. There is an acute urgency, which indicates that human beings are running out of time to manage climate change. Now is the time to consider unconventional approaches, including geoengineering and glacier engineering (Bodansky & Hunt, 2020). This chapter builds on Amartya Sen's development concept by suggesting that developing countries may look toward targeted geoengineering from a development perspective. This aspect of targeted geoengineering becomes apparent when we look at the rapid melting of glaciers in South Asia, hurting South Asian countries' development.

Development concerns have permeated discussions of adaptation and mitigation but much less about SRM and CGE, and this project seeks to address that gap. There are some obvious sources of global South disengagement from CGE debates. CGE is not seen to solve their problems, which are much more related to development, like poverty, energy, and livelihoods. Mistrust of technology developed by the global North is likely to be designed to benefit the global North. Finally, there is a lack of agency, which results in technologies the global South cannot control. By framing CGE as a response to development concerns, this dissertation seeks to provide a more appealing basis for the policy community in the Global South, specifically in South Asia, to engage in debates over the future of CGE.

Definition and Approach to Just Development under the Capability Approach

The Capability Approach presents a distinctive perspective on development, conceptualizing it as a process that expands the real freedoms and opportunities available to individuals, enabling them to lead lives they have reason to value (Sen, 1999). This approach goes beyond mere economic growth

or the accumulation of wealth, emphasizing enhancing the actual living conditions of people by improving their capabilities. According to Sen, development should not be assessed solely based on economic performance but on how effectively societies create conditions that allow individuals to thrive. These conditions encompass meeting basic material needs, facilitating political and social participation, ensuring access to education and healthcare, and safeguarding individuals from discrimination and violence (Alkire, 2002).

Amartya Sen differentiates functionings and capabilities as key concepts in the Capability Approach. Functionings refer to various states of being and doing, such as being well-nourished, having shelter, or receiving an education. In contrast, capabilities represent the real freedoms or opportunities individuals have to achieve these functionings (Sen, 1999). This distinction is crucial: while functionings describe the outcomes, capabilities illustrate the opportunities available to achieve those outcomes. Consequently, development focuses on enhancing individuals' capabilities to lead lives they value (Nussbaum, 2000). This comprehensive perspective on well-being encompasses material wealth and non-material elements like social freedoms, self-respect, and cultural belonging, which are central to the Capability Approach (Robeyns, 2005).

According to the Capability Approach, development is not a one-size-fits-all concept. Its primary goal is to expand people's freedoms and capacity to choose and pursue a life they value. This perspective significantly shifts from earlier development models prioritizing economic growth or material wealth. Amartya Sen argues that development should focus on broadening the range of choices available to individuals rather than merely concentrating on wealth accumulation (Sen, 1999). It enhances human freedoms across various dimensions—economic, political, social, and personal (Sen, 1999). Increasing these freedoms empowers individuals to take charge of their lives and make meaningful decisions. For instance, while economic growth may result in higher incomes, without the freedom to use that income for education, healthcare, or engagement in community life, individuals may not derive true benefit from it (Alkire, 2002).

In practical terms, this implies that development should eliminate obstacles restricting individuals' freedom, including poverty, illiteracy, poor health, and social exclusion (Sen, 1999). These barriers hinder people's ability to transform their resources into meaningful outcomes. Consequently, policies should prioritize enhancing economic productivity while ensuring that individuals can effectively utilize their resources to improve their quality of life (Nussbaum, 2000).

As framed within the Capability Approach, a just development emphasizes equity, freedom, and agency. It necessitates that development initiatives promote fairness and justice in the distribution of capabilities among individuals and various social groups. This focus is crucial, as individuals often encounter unequal circumstances that hinder their capacity to convert resources into functionings (Robeyns, 2005). A fundamental aspect of just development is the commitment to addressing inequality, not solely in income, but in the broader context of unequal capabilities (Sen, 1999).

A key characteristic of just development is the emphasis on ensuring equity in capabilities. Just development prioritizes ensuring that all individuals, irrespective of their background, have access to the opportunities necessary to lead a fulfilling life. This approach considers the various barriers people encounter due to gender, ethnicity, location, and disability (Nussbaum, 2000). For instance, a just development framework would acknowledge that marginalized groups often require additional support to attain the same capabilities as others. Thus, just development is inherently pluralistic, understanding that different individuals and communities may prioritize different functions and that development must embrace these diverse values (Alkire, 2002).

Sen underscores that freedom is the primary objective and the essential means of development. Essentially, development seeks to enhance freedoms and depends on them as a mechanism for further progress (Sen, 1999). For example, political freedoms—such as democracy and freedom of speech—are instrumental in improving individuals' lives and are valuable as they empower people to shape their society (Robeyns, 2005). Expanding freedoms fosters improved health, education, and economic outcomes, thus creating a virtuous development cycle.

Just development is characterized by its emphasis on agency, which refers to the capacity of individuals or groups to act independently and make their own choices. Therefore, development should empower people to actively shape their own lives rather than merely serving as passive recipients of aid or assistance (Sen, 1999). Achieving just development requires creating conditions that allow individuals to express their preferences, participate in collective decision-making, and hold institutions accountable. This is essential for fostering sustainable development, as it encourages individuals to take ownership of the development process (Nussbaum, 2000).

Ultimately, just development underscores the importance of sustainability, ensuring that present generations can fulfill their needs without jeopardizing the ability of future generations to do the same. This involves confronting environmental degradation, resource depletion, and social inequalities that could hinder long-term well-being (Alkire, 2002). A just development approach

necessitates that policies consider immediate benefits and the future capabilities of individuals and societies.

A Normative Framework for Just Climate Geoengineering Based on the Capability Approach

The Capability Approach, formulated by Amartya Sen, provides a robust and ethically grounded framework for assessing the justice and fairness of climate geoengineering initiatives. When applied to this field, the approach prioritizes the expansion of human freedoms, the enhancement of well-being, and the assurance that both the processes and outcomes of climate-related interventions are equitable, inclusive, and just. Geoengineering refers to the deliberate manipulation of the climate to mitigate the effects of climate change, primarily through two methods: CDR and SRM. Both methods offer considerable benefits but pose significant risks, especially for vulnerable populations. Consequently, evaluating climate geoengineering's impact on well-being is essential.

Any claim that an assessment of capability must be a good guide to the well-being of a person must be restrained by the understanding of two important distinctions: (1) the contrast between agency and well-being and (2) the distinction between freedom and achievement. (Sen, 1999, P.287).

This quote from Amartya Sen highlights two crucial distinctions necessary for accurately assessing a person's well-being through their capabilities. Sen argues that understanding these distinctions is essential to avoid oversimplifying well-being. Agency refers to a person's ability to pursue their values and goals, even if these goals do not directly improve their well-being. In contrast, well-being is more about personal welfare and quality of life. Sen suggests that a person's agency may lead them to prioritize actions that are meaningful or fulfilling to them but do not necessarily directly enhance their well-being. Therefore, assessing well-being solely through capabilities would miss this nuance if it doesn't account for agency. Freedom is the range of options available to people—their ability to choose and act independently. Achievement, on the other hand, is the actual outcome or accomplishment of these choices. Sen points out that well-being is not solely about what people achieve but also their freedom to choose. Two people might achieve the same outcome, but their sense of well-being might be different if one had fewer choices or freedoms in reaching it. Together, these distinctions emphasize that well-being assessments should consider what people can achieve (capabilities) and respect the broader dimensions of agency and freedom. This nuanced approach

recognizes that well-being involves having the freedom to choose, the ability to act on those choices, and the fulfillment that comes from agency.

A just approach to climate geoengineering must primarily enhance the well-being of individuals and communities, particularly those most vulnerable to the impacts of climate change. This approach aligns with the Capability Approach, which emphasizes expanding people's genuine freedoms to lead lives they value. Any geoengineering intervention should prioritize minimizing harm while maximizing benefits to human health, livelihoods, and the environment. Furthermore, geoengineering should be integrated with broader development goals, ensuring that interventions mitigate climate change and promote sustainable economic and social development. For instance, CDR techniques such as afforestation or bioenergy with carbon capture and storage (BECCS) could create jobs, improve ecosystem services, and boost agricultural productivity, thereby enhancing the well-being of local communities. Avoiding unintended negative consequences, such as regional weather disruptions or environmental degradation, which could disproportionately affect marginalized populations, is essential. Protecting communities from harm—whether from climate change or the geoengineering interventions themselves—is a cornerstone of a just strategy.

The second component of just climate geoengineering is inclusivity in processes. This means that affected communities, especially those most vulnerable to climate change, should have a meaningful role in decision-making.

The freedom to choose our lives can significantly contribute to our well-being, but going beyond the perspective of well-being, the freedom itself may be seen as important. Being able to reason and choose is a significant aspect of human life. (Sen, 2009, p.18)

Geoengineering governance structures must be inclusive, enabling participation from local, national, and global stakeholders in discussions regarding deploying these technologies. Communities must be fully informed about geoengineering interventions' risks, benefits, and uncertainties before implementation. Transparency goes beyond merely providing information; it fosters trust and confidence. This approach ensures that individuals are not subjected to technologies that could jeopardize their livelihoods or well-being without their knowledge or consent. Furthermore, free agency entails individuals having the resources and opportunities to adapt to any changes by geoengineering, be it through social safety nets, economic compensation, or access to alternative livelihoods.

The third component of just climate geoengineering is self-governance. A just approach to geoengineering must incorporate robust and transparent governance structures that honor global and local contexts. Given that the effects of geoengineering interventions, such as SRM, can transcend borders, governance mechanisms should empower local self-governance while also integrating regional and global oversight. Institutions should be adaptable to meeting different regions and communities' specific needs and concerns.

There have also been remarkable changes beyond the economic sphere. The twentieth century established democratic and participatory governance as the preeminent model of political organization. Concepts of human rights and political liberty are now very much part of the prevailing rhetoric (Sen, 2009, p.xi).

Institutions responsible for geoengineering must uphold a fiduciary duty to prioritize the long-term well-being of people and the planet. This means that decision-makers should focus on the needs of the most vulnerable populations, ensuring that no group is disproportionately harmed or excluded from the benefits of geoengineering initiatives. Decisions should be made transparently, with robust checks and balances to hold geoengineering projects accountable to the communities they impact. Establishing independent oversight bodies could be beneficial in monitoring the effects of geoengineering interventions, ensuring they adhere to principles of justice and equity.

The fourth component of equitable climate geoengineering is ensuring justice in outcomes. A fair geoengineering strategy should enhance justice by ensuring that the benefits of these interventions are distributed equitably while minimizing and fairly distributing any negative impacts. This requires particular attention to vulnerable and marginalized populations, who are often most at risk from both climate change and potential side effects of geoengineering.

Having greater freedom to do the things one has reason to value is (1) significant for the person's overall freedom, and (2) important in fostering the person's opportunity to have valuable outcomes. (Sen, 2009, p. 18).

Geoengineering interventions must be designed to avoid worsening existing inequalities. For instance, while SRM techniques may reduce global temperatures, they could also lead to droughts or extreme weather events in certain regions, which must be mitigated. Equity requires that those who benefit from climate policies, often wealthier nations or regions, bear the associated costs, while vulnerable

areas should receive compensation or protection against potential harm. A just approach to geoengineering must be based on a comprehensive social impact assessment.

This normative framework can be utilized to assess SRM and CDR to ensure they adhere to just and equitable standards. SRM, which seeks to reflect sunlight to cool the Earth, presents significant risks due to its potential impact on global weather patterns. A just approach to SRM must prioritize the well-being of those most vulnerable to climate disruptions and ensure that any decision to deploy SRM is made democratically, with the informed consent of affected communities. It should also include globally accountable governance structures, ensuring a fair distribution of benefits and risks across different regions.

Conversely, CDR offers more concrete opportunities to align with development goals. Techniques such as afforestation, BECCS, and soil carbon sequestration remove CO₂ from the atmosphere while providing co-benefits like enhanced biodiversity, job creation, and increased agricultural productivity. To ensure justice, CDR projects should focus on the needs of developing countries, which are particularly vulnerable to climate change and often lack adequate resources for adaptation. The implementation processes for CDR must be transparent and inclusive, allowing local communities to have a voice in shaping and benefiting from these initiatives.

A just approach to climate geoengineering, grounded in the Capability Approach, must prioritize human well-being, ensure inclusive and democratic processes, be governed transparently with a focus on equity, and produce outcomes that enhance justice while safeguarding the most vulnerable populations. This normative framework offers ethical guidance for designing and implementing climate geoengineering strategies that mitigate climate risks and promote sustainable development, global fairness, and climate justice.

Chapter 2: The Capability Approach as an Equity Framework for CGE Research and Governance

Introduction

CGE, encompassing strategies like CDR and SRM, has often been framed as a technical solution to mitigate climate change risks. However, this narrow perspective overlooks its potential to be integrated within a justice-oriented development framework. Reframing CGE as just development shifts the focus from merely managing climate risks to addressing the broader needs of equity, well-being, and sustainable growth, especially in the global South. This perspective recognizes that climate change is an environmental and developmental challenge, threatening livelihoods, economic stability, and social justice (Shepherd & Dissart, 2022).

The global South, disproportionately affected by climate change, faces systemic vulnerabilities due to limited resources and structural inequalities. By viewing CGE through the lens of just development, it becomes possible to align climate responses with national and regional development priorities. For instance, CDR techniques can simultaneously reduce atmospheric carbon levels and generate economic opportunities through carbon credit markets or sustainable land-use practices (Frank et al., 2024). Similarly, targeted SRM interventions can address immediate regional challenges, such as glacier protection, while safeguarding long-term water and agricultural security (Duffey et al., 2023).

Amartya Sen's Capability Approach offers a robust theoretical foundation for this reframing. It emphasizes enhancing freedoms and opportunities, allowing individuals and communities to pursue lives they value (Sen, 1999; Sen, 2009). Applying this framework to CGE research and governance ensures that solutions are technologically feasible, socially inclusive, ethically grounded, and aligned with developmental goals. This reframing positions CGE as a tool to enhance adaptive capacities, reduce inequalities, and promote sustainable development rather than perpetuating existing inequities or creating new risks. By integrating CGE into the broader agenda of just development, policymakers can ensure that climate responses contribute to a more equitable and resilient future.

Traditionally, climate change has been viewed as the responsibility of developed countries. However, this is no longer the case, as the global South's contribution to emissions is significant, with a rising trend (IPCC-AR6, 2023). Unlike the Kyoto Protocol, the Paris Agreement now places a positive

obligation on the global South to mitigate (UNFCCC, 2015, Article 4). The higher vulnerability levels in the global South also necessitate a focus on climate responses. The IPCC has identified CDR and SRM as potential climate responses (IPCC, 2018). I will delve into the complex definitional issues below. CDR is now considered by the IPCC as 'unavoidable,' while SRM, although still viewed as highly risky, remains a part of the climate discourse (IPCC-AR6, 2023).

Despite the increasing significance of CGE, developing countries have not had a substantial role in shaping these technologies or their governance (Rehman et al., 2018; Biermann & Möller, 2019). The global South often views these climate responses with mistrust and cannot meaningfully participate in the discourse. This situation underscores the necessity of examining CGE from a developing country's perspective and priorities, essentially from a development perspective. It is crucial to understand that climate change poses a significant obstacle to achieving development goals in developing countries, and that climate actions and solutions must be integrated into these goals (Asian Development Bank, 2021, p. 01). One potential development perspective that offers a broad and justice-oriented view of development is Amartya Sen's idea of development as freedom under the capability approach (Sen, 1999). The capability approach is a multi-dimensional theoretical framework that explicitly addresses the justice-based foundations of development.

There are serious calls to analyze CGE as a potential climate policy option, adaptation, and mitigation. The current climate policies alone are unlikely to deliver the global community agreed in the Paris Agreement (2015). This underscores the crucial need for international cooperation in the fight against climate change. Article 2 of the Paris Agreement sets ambitious targets for limiting the global average temperature by "holding the increase in the global average temperature to well below 2°C above preindustrial levels and pursuing efforts to limit the temperature increase to 1.5°C above preindustrial levels" (Paris Agreement, 2015, p.3). The Paris Agreement has set ambitious goals for reducing carbon emissions and limiting global average temperature, but there appears to be limited success so far (IPCC-AR6, 2023; Asayama & Hume, 2019; Lawrence et al., 2018). The current Nationally Determined Contributions (NDCs) implementation can result in a global average temperature increase of 3°C by the end of this century (UNEP, 2020). The current emission reduction pathways are inconsistent with the goals set under the Paris Agreement (IPCC, 2018, p. 20). The mitigation schemes can lead to pathways restricting temperature to 1.5 °C with no or limited overshoot, but CDR is critical to attaining these goals (IPCC-AR6, 2023; Honegger et al., 2018; Bellamy & Geden, 2019). According to IPCC:

Carbon dioxide removal (CDR) will be necessary to achieve net-negative CO₂ emissions. Achieving global net zero CO₂ emissions, with remaining anthropogenic CO₂ emissions balanced by durably stored CO₂ from anthropogenic removal, is a requirement to stabilize CO₂-induced global surface temperature increase (IPCC-AR6, 2023, p.50).

To attain the desired carbon removal results, the CDR needs to be deployed at a much larger scale which needs the participation of developing countries. The complete optimization of CDR solutions will require considerable time and effort, which is a long-term process; therefore, there is a need for continued research on CDR as a climate policy option (Craik, 2023). In coming years, policymakers will consider scaling up CDR to restrict global warming by 1.5 -2 °C. CGE research is important because of the unlikely ability to meet the Paris Agreement’s emission reduction goals in the absence of large-scale deployment of CDR (IPCC-AR6, 2023, Fuss et al., 2016) and the potential need to moderate peak temperatures (possibly through SRM) to avoid catastrophic loss and damage (Ott, 2018). The figure below presents a portfolio or integrated approach of various warming scenarios with or without certain climate policies:

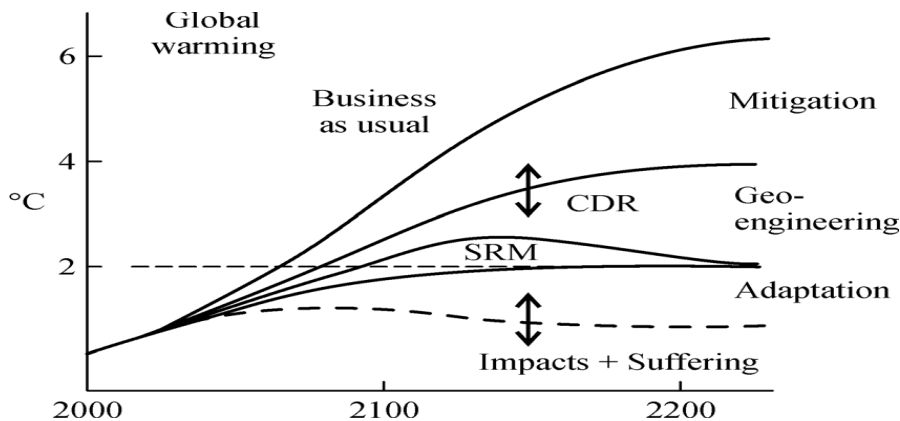


Figure 3: Long and Shepherd "Napkin" Diagram

A strategic approach to a portfolio of responses to climate change. Note: the line for impacts and suffering, after these have been reduced by adaptation, is drawn hatched, since these cannot be located on a simple temperature scale. The intention is to show the level of impacts and suffering that would correspond to a lesser degree of warming without adaptation for comparison (Long & Shepherd, 2014, p.765).

Anthropogenic climate change threatens human well-being, capabilities, freedoms, and development in many parts of the world. Climate change can severely harm human and non-human capabilities in developing countries if national governments or international institutions do not take appropriate measures (Lyster, 2017). Due to the poor economic situation and low budgetary allocation for adaptation and mitigation measures, many developing countries are less resilient against climate change (Lyster, 2017).

Like many other issues in international relations and global governance, the global North has predominantly influenced the discourse of climate change debates (Najam, 2005). The CGE research is no exception in which Western scholars have led the debate. However, the existing scholarship has had limited engagement with analyzing CGE in the context of a developing country's justice perspective. Too much focus on framing CGE as a techno-fix approach to manage climate risks and related uncertainties has diverted our attention from the original point, which is to use all possible means to avoid worsening climate change. There are some reservations about the risks involved in the research and deployment of a few techniques of CGE. The international community has expressed concern over geoengineering and sought to curtail CGE activities through resolutions adopted by the parties to the Convention on Biodiversity (CBD) and the London Protocol. The amendments to the London Protocol were adopted in 2013, but they are not in force. However, concerning CDR, the degree of controversy is unclear. It would likely depend on the scale and nature of deployment of CDR due to the potential impacts of large-scale CDR on key systems such as energy, land, and water (Anderson et al., 2023). The acceptability of CGE proposals will be technology-dependent and context-dependent (Buck, 2021).

As discussed in Chapter 1, the unjust pattern of the north-south relationship in a scholarship starts from the marginal representation of scholars from developing countries at the early stage of scholarship and the lack of participation from the global South to actively understand subjects like CGE. The academic debates regarding SRM's research and governance have been dominated by a limited number of scholars, primarily from the global North (Biermann & Moller, 2019; Flegal & Gupta, 2017). Most empirical studies on public perception of SRM have also focused on developed countries (Burns et al., 2016), and very few publications have focused on the participation of developing countries regarding CGE governance (Biermann & Möller, 2019; Moller, 2019; Sugiyama et al., 2020). Due to the lack of participation of scholars from developing countries, scholars from the global North might have missed some crucial insights and general perspectives regarding SRM research, which

could be vital for understanding the global South's approach to SRM's governance (Hourdequin, 2018). The limited representation of southern scholars and the resultant lack of diversity in CGE debates creates epistemic challenges by framing crucial concepts like equity in a specific and restricted manner (Flegal & Gupta, 2017). More voices from the global South are essential for SRM research and governance to make it more legitimate and credible (Winickoff et al., 2015). These epistemic challenges highlight a possible understanding gap in CGE research and governance between the global North and the global South. There is a need to bring geoengineering debates out of "Western bias" (Sugiyama et al., 2020, p. 642) or capitalist influence (Sapinski et al., 2021, p. 12) to objectively evaluate CGE research in the context of developing countries.

One possible way to address this marginal representation of developing countries in CGE scholarship is to apply different theoretical frameworks to allow diverse perspectives about CGE. Applying different theoretical lenses to CGE governance would enrich the academic debate and attract global south policymakers' attention to explore CGE as a potential option to address climate change-related issues. The change of theoretical lens can redefine the problems, issues, and solutions in CGE research. Holly Buck has used different approaches to understand the relevance of CGE in global environmental governance. Earlier, Buck noted that CGE has a negative perception, restricting our imagination about CGE's potential benefits for people who need intervention like SRM that could help to address the existential threat from environmental challenges (Buck, 2012). Later, Buck believed that most of the risks associated with CGE are particular to the context in which the technologies are researched and developed (Buck, 2021). In addition, Biermann highlighted the marginal representation of the global South in CGE debates and later argued for placing a moratorium on SRM research (Biermann & Möller, 2019; Biermann, 2021). Generally, developing countries have argued for an environmental justice framework while advocating for historic emissions as the central base for action while dealing with climate change-related issues.

In the case of CGE governance, the framework of climate justice can also be relevant (Flegal & Gupta, 2017; Horton & Keith, 2016; Rahman et al., 2018; Batres et al., 2021). While acknowledging the crucial role of the global South in CGE, current equity approaches ignore the global South's crucial perspectives on climate change. IPCC (2018, p.55) has discussed four "framing asymmetries" that can help understand how climate change and climate policy options like adaptation, mitigation, and CGE differ in nature and application in the global South than in the global North. First, asymmetry is about the differential contributions to the problem, as developed countries have greatly benefited from

industrialization, and developed countries bear greater responsibility for addressing climate change. The second asymmetry is about differential impact, as climate change adversely affects those who are least responsible (mainly developing countries) for the deterioration of the environment. The third asymmetry, particularly relevant to CGE governance, is the limited capacity of adversely affected nations to formulate strategies to address anthropogenic climate change. Fourth, asymmetry is about future response capacity. Some people and places will be far behind others in a path of low-carbon development, which is much needed to avoid climate change-induced disasters. The existing equity approaches to CGE governance do not fully consider these asymmetries nor analyze CGE to attain development or protect capabilities threatened by climate change. The development issue has remained critical for the global South's engagement in global environmental governance (Najam, 2005). By focusing on development, CGE research can attract developing countries' attention to engage more scholars and policymakers, as the idea of development has remained a lynchpin of national policies in many developing countries.

I will explore the relevance of CGE research for developing countries and how it fits into their climate policy options. I will also discuss some existing equity debates regarding CGE research and its limitations. This chapter uses the lens of the capability approach of Amartya Sen to examine the critical issues of CGE research. The chapter is divided into four parts. The first part addresses the definitional dimensions of CGE, which are a source of controversy, including the decision to lump or split CDR and SRM (Jinnah et al., 2021). CDR reduces CO₂ in the atmosphere, which is expensive and slow but a form of mitigation. It is also a potential form of development as it may generate carbon credits and lead to carbon cooperation and trade under mitigation outcomes, as Article 6 of the Paris Agreement suggests. Global SRM is a stop-gap measure conditional with peak shaving or harm reduction and closer to an adaptation approach. Targeted SRM is more aligned with adaptation, and it does not affect global temperature but instead addresses the effects of warming on specific features that a country or group of countries seeks to prevent. Part two, in essence, is a literature review on CGE and the global South. It discusses debates, concerns, and current framings and critically assesses what is missing from them. It justifies why it is essential to look at capabilities. The 3rd part discusses various dimensions of the capability approach and Sen's approach to justice generally, as it mainly focuses on drawing out the specific relevance of the capability approach for CGE research and governance. The inequality in access to advanced scientific intervention, especially in developing countries, can lead to social justice issues, and the capability approach provides a framework to analyze the situation (Arambala, 2020).

Section 4 presents an analytical framework based on Amartya Sen's approach to pathways to CGE. This framework can help to understand the global South's disengagement from CGE scholarship and policymaking and why developing countries must join these debates, especially on justice issues of CGE. However, so far, CGE debates have focused on concerns of developed states. In this situation, Sen's capability approach is an appropriate approach that provides a framework to assess approaches and pathways for CGE.

The analytical framework is primarily based on insights from the capability theory of Amartya Sen and contributions from other scholars like Martha Nussbaum. The framework has also been shaped by various case studies in which the application of the capability theory has been discussed. The first element of the analytical framework is objective. By the program's "objective", I understand any CGE program's normative basis and direction. As CGE research is attributed with many risks, the second element of the framework is "processes" crucial to determine when to start and end a CGE technique, who will participate in the decision-making processes, and what prerequisites are essential to join the decision-making processes. The third element of the framework is "institution/governance". In this framework, governance parameters are the broader contours for addressing ethical, social, and economic issues concerning CGE research and deployment. These parameters can help to address issues like accountability and transparency, moral hazard, termination shock, and liability. The final component of the analytical framework is the "outcome". It is the evaluation of a CGE program to determine how it has contributed as a climate policy option. The final part of this chapter is the conclusion, which discusses future research and how the framework I have developed may be used to assess different approaches to CGE and critical debates. This framework can provide a theoretical base through which scholars and policymakers from the global South can see relevance regarding CGE research and governance according to their national and international context.

CGE Governance and the Climate Justice Debate

Scientific knowledge and climate modeling may help policymakers determine CGE's distributional impacts, but that does not thoroughly guide decision-making processes. Scholars and policymakers must answer fundamental questions like who will participate in the negotiation, pay the damages if CGE has adverse effects, and decide when to start or shut down large-scale climate intervention. There is a need for a comprehensive theoretical framework to evaluate the CGE research and governance. A critical consideration in applying any theoretical framework to CGE governance is the ability of the

theoretical framework to address the global South's growing emphasis on ethics, justice, and development in global environmental governance. An ethical approach can legitimize a regime in international affairs (Rosenthal, 2020). CGE governance can gain legitimacy in developing countries by placing climate justice and development at the core of CGE research. A legitimate CGE research program with broader public support can help the national and subnational governments to make inclusive policies, allocate a budget, and design CGE research according to their respective national climate change plans.

A justice-based argument for CGE governance is to address climate injustice through a certain level of deployment of CGE. SAI can be a remedy to mitigate the effects of increased emissions, which have historically benefited developed countries at the cost of developing countries (Svoboda et al., 2019). The "countries with high emissions, particularly those with high cumulative historical emissions, have a greater responsibility to implement CDR" (Honegger et al., 2021). In this way, CGE can be a potential tool to respond to climate injustices that wealthy industrialized countries have created through their economic activities. Developing countries receive adverse effects of increasing global emissions because of developed countries' industrial and economic activities but without significant benefits.

The "developing countries have the most to gain or lose. In our view, they (developing countries) must maintain their climate leadership and play a central part in research and discussions around solar geoengineering" (Rahman et al., 2018, p.23). When there is a broader consensus that developing countries have suffered more from climate change, why should developed countries dictate the terms for CGE governance? (Hourdequin, 2018, p.283) However, this assertion is incomplete because expecting developing countries to lead in CGE research and governance due to their vulnerability is an inconclusive argument. It does not consider the development aspirations of developing countries and how developing countries themselves can use CGE as a climate policy option. The point of giving a greater voice to the GS would be to allow for considerations of development aspirations.

The second equity rationale for CGE governance is to benefit the world's poor people. SRM's consideration as a climate policy option can benefit people experiencing poverty (Horton & Keith, 2016). Developing countries have fewer resources than rich countries to manage climate risks and pursue mitigation and adaptation goals (Horton & Keith, 2016). The "global distributive justice principles seriously entail a moral obligation to research solar geoengineering" (Horton & Keith, 2016, p. 79). According to this approach, developing countries' economic constraints are obstacles to limiting carbon emission goals through adaptation and mitigation alone. However, Hourdequin (2018,

p. 283) has criticized this approach because Horton & Keith's (2016) argument is based on distributive justice while ignoring the procedural aspect of justice. Hourdequin believes that pro-poor is a weak rationale because it promotes paternalism and denies agency to the poor, as developed countries will evaluate good and bad things for developing countries based on their own experience. This equity rationale also creates cultural parochialism, meaning a particular view is treated as having universal acceptance. This idea of Hourdequin resonates with Amartya Sen's approach, which advocates differentiating between Western democratic values and the economic needs of people living under the poverty line (Sen, 1999). In addition, the pro-poor approach ignores the concerns related to the governance of SRM and merely focuses on results. Finally, this approach supports expert imperialism as developed countries dominate the debate and promote a particular narrative (Hourdequin, 2018, p. 283). Similarly, Flegal & Gupta (2017, p. 53) argue that Horton and Keith advocate "speculative ethics" by rating SRM as a better option than adaptation and mitigation for vulnerable communities.

The third justice-based rationale for CGE governance is based on the assertion that the IPCC's climate models for attaining the emission reduction goals under the Paris Agreement contain tacit endorsement for CGE's research, especially CDR (Horton et al., 2016, p. 3; Flegal & Gupta, 2017, p. 55). The ambitious goal of Article 2 of the Paris Agreement is "to limit the temperature increase to 1.5°C above preindustrial levels" (Paris Agreement, 2015, p. 3). It appears quite challenging when most climate models suggest that existing adaptation or mitigation efforts may not be enough to meet these goals (IPCC, 2018). No scholar has read Paris Agreement to provide an endorsement of the use of SRM; rather, the temperature target was intended to require ambitious mitigation (Suarez & van Aalst, 2017, p. 183). Even if there is a broader consensus between the global North and the global South regarding emission reduction goals in the Paris Agreement, it does not mean that the global South and the global North have similar resources and circumstances to attain these ambitious goals under the Paris Agreement. The authors of the Paris Agreement were aware of the capacity challenges of developing countries, and they recognized this factor in the agreement (Lyster, 2017, p. 446). This equity rationale for CGE research and governance based on the goals set in the Paris Agreement may be desirable but does not consider developing countries' actual situation. The temperature targets in the Paris Agreement and the net-zero approach in Article 4 are pushing countries towards CDR, and this is becoming apparent. For the global south, the concern is that they may not be able to participate in CDR, particularly if the technology is not transferred and capacity is not developed. The Paris Agreement explicitly recognizes this aspect and has many references to equity and CBDR and mechanisms to address but these are, to date, poorly implemented. Instead of genuinely co-creating

CDR technologies, the approach seems to be that the North will create and maybe share technologies, but the mechanisms required are very weak. Most developing countries lack the financial and technical capacity to pursue ambitious goals even through CDR or SRM. Every country in the global South is unlike China or India, which have significant human resources, financial depth, and technological advancement to embark on a challenging journey of CGE research.

All justice-based rationales discussed above that analyzed the CGE governance have enriched the CGE scholarship; however, there are some common issues with all these equity rationales. As a standalone approach, SAI has been evaluated for potentially violating all three aspects of justice: distributional, intergenerational, and participatory (Svoboda et al., 2011). First, these equity rationales fail to recognize the importance of the participatory aspect of justice and primarily focus on distributional aspects. As stated earlier, a benefit of earlier engagement of developing countries in CGE research and governance debates is that developing countries can influence CGE's governance. The sole focus on the distributional aspect compromises the spirit of social justice. Any environmental policy, including CGE, must be sensitive to distributional and participatory aspects. For example, community involvement is critical in the case of CDR, in which there is the possibility of change in land use and subsequent implications on local agriculture and governance structures depending on the scale of CDR. Therefore, advocating for a more inclusive and socially responsible framework in CGE governance is crucial to ensure that all voices are heard, and all impacts are considered.

Moreover, the existing equity rationales for CGE governance pay less attention to countries' rights and duties. The "rights are protections and entitlements about corresponding duties and responsibilities" (Rosenthal, 2020). The environmental justice movement allows developing countries to explore the viability of CGE for their national climate responses. On the other hand, the climate justice movement places a fiduciary duty on developed countries to assist developing countries in protecting their capabilities threatened by climate change. The "proposed benefit of the fiduciary approach arises not only because of a government's legal duty to their own citizens, but also an extension of this legal duty to all of the world's people" (McGoldrick et al., 2016, p. 10). Without a complete understanding of rights and duties, any theoretical framework for just CGE will be incomplete. In the case of CGE, there is a legal and moral duty to exercise control associated with CGE in favor of those most affected. This provides a strong link to Sen's use of fiduciary and provides a basis for attributing responsibility. This is important in the BRI case study and the HKHK case study. These case studies suggest that China, by creating conditions that affect the climate future of host

countries, owes an obligation to assist them in addressing those problems (along with other developed states). Another aspect of the debate is whether the BRI is structured to fulfill that responsibility.

The existing justice-based rationales treat CGE technologies as socially acceptable and ignore possible social and cultural implications for emerging technologies in developing countries. Any branch of science, including CGE, cannot be immune to societal and cultural influences. The “scientific claims are subject to distortion, through imperfections in the very human system that produce them” (Jasanoff, 2006, p.339). CGE is an innovation, and it is the role of scientists, scholars, and policymakers to be sensitive to the world's diverse societal and political dynamics (Long, 2016). Their understanding and consideration of these influences are crucial for advancing responsible innovation within CGE research and governance (Rayner et al., 2013; Stilgoe et al., 2013; Hubert, 2018). Stilgoe et al. (2013) have devised a four-point framework for CGE’s responsible innovation and governance. This framework’s components are anticipation, reflexivity, inclusion, and responsiveness. Many other scientific innovations are also going through social and political evaluations, like genetically modified organisms (GMOs), artificial intelligence (AI), and data sciences (DS). Therefore, it is crucial to highlight the need for sensitivity to social and cultural implications to make the audience feel valued and integral to the process.

The existing equity rationales for CGE governance focus on the north-south dimension but ignore emerging south-south cooperation regarding climate change and transnational development initiatives like China’s BRI. Accepting this diversity and the emergence of a new dimension of global governance is vital for understanding the implications of any climate policy option like CGE. There is a need for a theoretical framework to analyze the south-south dimension regarding the governance of CGE. The reflexivity suffers if innovators are not cognizant that a theoretical frame cannot be globally applicable, and to make a responsible innovation inclusive, dialogue on various framing assumptions is essential (Stilgoe et al., 2013). The existing justice-based rationales for CGE governance treat the global South as a homogenous group, but the global South collates diverse groups of countries with different climate policy needs. A framework that supports CGE research and governance bottom-up and aligns with the interests of the host countries and local communities is necessary and empowering for these communities.

Finally, the existing equity rationales for CGE governance focus on the global South’s victimhood while ignoring the development aspirations of many developing countries. Developing countries' approach

to climate change differs from developed countries. In developed countries, the main effort is to understand and address environmental issues like emission reduction or limiting global average temperature increases. While in developing countries, climate change is seen as a threat multiplier that can exacerbate poverty levels, malnourishment, and climate-induced migration (IPCC-AR6, 2023). Many developing countries seek concession in global climate change negotiations regarding emission reduction targets, emphasizing adaptation and loss damage. The point seems more a process one, given that diversity must be paid to distinct views from different countries. It is less of a challenge for CDR (but still perhaps a concern at local levels) but a more significant problem with SRM, which effectively removes choice from countries.

Capability Approach

The capability approach is a theoretical framework for just development primarily developed by Amartya Sen (1980, 1999, 2009) and expanded by many other scholars like Nussbaum (2007, 2011), Alkire (2005), and Robeyns (Robeyns & Byskov, 2020). The capability approach began in response to utilitarianism and redefined the concepts of human well-being and development (Kimhur, 2020). The capability approach can be broadly considered a theory of justice that stands between utilitarianism, which emphasizes outcomes like utility and pleasure as the basis for equity, and the Rawlsian approach, which emphasizes abstract principles such as free speech or essential income attainment (Arambala, 2020). From the CGE perspective, scholars like Horton and Keith rely overly on a utilitarian approach; they justify SRM on its overall aggregate benefit for humanity. Others, like Hourdequin, rely on a deontological approach rooted in abstract principles. The debate is hard to resolve because the conceptions of justice are not aligned. The utilitarianism and Rawlsian approach fail to appreciate that their goals are not ends but are means of achieving human fulfillment.

The capability perspective allows for an all-encompassing assessment of individual advantages insofar as it centers its account of development in the “comprehensive opportunities” the person is capacitated to pursue, and the extent of their freedom to achieve certain life functionings (Arambala, 2020, p. 1238).

The justice theory under the capability approach provides a theoretical base for analyzing CGE research and governance from the equity perspective. There are two schools of thought about the theory of justice within the capability framework. The first group argues that any theory of justice needs to meet specific prerequisites to meet the capability framework’s standards; however, the

opponents argue that instead of developing an ideal theory, the focus should be more on reducing capability deficiencies (Robeyns, 2017). I agree with the latter approach within the capability framework because ensuring social and environmental justice is a continuous goal, and addressing injustice is appreciable.

The capability approach is a flexible and multidimensional theoretical framework, not a particular theory (Robeyn, 2017). The capability approach has two key arguments: freedom is vital to attaining well-being, and criteria for determining well-being should be based on capabilities and functionings (Robeyns & Byskov, 2020). The capability approach emphasizes that income or GDP is not the sole criterion of well-being. To attain well-being, people should have enough positive resources to make meaningful choices (Alkire, 2005). Positive resources include access to education, health facilities, and sustainable transport. In South Asia, during the monsoon season, due to heavy rains and the melting of glaciers, floods cause damage to road and rail infrastructure, and some areas get cut off from the rest of the country. This situation can deprive people of health, food, and educational facilities, leading to deprivation of capabilities that cannot be fully explained by income alone. This relates to climate change as a source of resource diminishment, and therefore, CGE, insofar as it addresses it, is a potential source of enhanced capabilities. I chose Sen to analyze CGE governance because of Sen's significant impact on the development concept and aligning it with developing countries' needs and ground realities. Some scholars have analyzed climate change from the capability perspective, but it is minor or negligible concerning CGE. The application of the capability approach in environmental scholarship includes adaptation (Schlosberg, 2012; Lyster, 2017), environment as meta capability (Holland, 2008), and sustainable development (Sen, 2013). Applying the capability approach to climate change issues becomes more relevant when we look at the destruction caused by climate change and capabilities compromised by disasters. The capability approach provides a solid foundation that supports analyzing CGE from the justice perspective. According to Lyster:

Invoking the capability approach to climate justice is especially justified when one considers that when disasters strike, the poor quickly exhaust limited resources, further undermining household sustainability. In the long run, this reduces capital and increases hazard exposure or vulnerability, while the poverty and vulnerability trap renders recovery to pre-disaster levels of well-being increasingly difficult (Lyster, 2017, p. 442).

The capability approach as a theoretical framework is relevant for analyzing CGE research because it can help to analyze CGE's role in protecting capabilities threatened by climate change. Sen's approach

is also a theory of development. Sen centers development within the context of justice (freedom) context. If we want to think about CGE as development, we must consider what kind of development is just. Sen provides an answer by looking at capabilities. Can CGE approaches be designed to increase capabilities (or reduce their diminishment) to give people greater freedom to make meaningful choices?

The capability approach is also compatible with existing climate governance institutions and approaches envisioned under the Paris Agreement. Individuals' freedoms and capabilities depend on the institutions they interact with (Sen, 1999, p.142). The Paris Agreement's bottom-up and procedural approach provides states and individuals with the agency to make climate choices. Also, the Paris Agreement addresses conversion factors by providing mechanisms for finance and capacity for climate policies. The capability approach preserves the degree of choice, emphasizes transparency and capacity, and takes the global North's responsibility seriously. The diplomatic success of the Paris Agreement (2015) is because the Paris Agreement integrated bottom-up and ratchet mechanisms, which allowed developing countries first to determine their national mitigation goals in consultation with local stakeholders and then become part of a global effort to limit global warming by 1.5- 2°C (Falkner, 2016). Regarding autonomy, the capability framework clearly states that any governance model should have democratic and participatory governance (Sen, 1999, p. Xi).

The capability approach towards development makes it relevant to analyze CGE to pursue a conducive environment where human capabilities can thrive. The capability approach argues for going beyond the traditional concept of development. This exercise partly includes and excludes the information base upon which the development concept is evaluated. According to Amartya Sen:

The excluded information is not permitted to have any direct influence on evaluative judgments, and while this is usually done in an implicit way, the character of the approach may be strongly influenced by insensitivity to the excluded information (Sen, 1999, p.56).

In this regard, Sen cites an example of famine and argues that famine was once considered a result of crop failure for a considerable time. However, gradually, it was realized that governmental policies like prices, irrigation, and agricultural research also contribute to famine and not just crop failure (Sen, 1999, p.183). We should be careful in attributing causal factors to intervening variables. Crop failure cause famines is apparent, but what is essential is to consider the human factors contributing to crop failures. Similarly, we must be careful to assume governance failures or inability to address issues like CGE without proper research and analysis. The following section will discuss some of the key

concepts of the capability approach. Potentially excluded information is affecting the CGE debate like scale and co-benefits. If the focus is on climate alone, CDR and SRM are evaluated solely on their contribution to that problem. They may downplay what is important to local communities, such as increased access to energy through BECCS, better agriculture through biochar, or enhanced adaptation through blue carbon. It is perhaps a question of weighting, and Sen's approach seems to require giving greater weight to individual and local capabilities.

Capabilities and Functionings

The concepts of capabilities and functioning are not just important but crucial to understanding the capability framework. As Robeyns (2017, p. 53) eloquently puts it, "capabilities are a person's real freedoms or opportunities to achieve functionings. Thus, while traveling is functioning, the real opportunity to travel is the corresponding capability". Sen has used these concepts to understand social issues like poverty, justice, and quality of life (Alkire et al., 2014, p. 2). The concept of functionings and capabilities provides a clear framework for understanding what a person has achieved, what is freely available for further achievement, and what a person values.

Functionings are 'doings and beings', that is, various states of human beings and activities that a person has achieved, such as being well-nourished, getting married, being educated, and travelling, while capabilities are the real, or substantive, opportunity that they have to achieve these doings and beings (Robeyns & Byskov, 2020).

Capabilities are also referred to as real or substantive freedoms that are readily available and free from any constraint (Robeyns & Byskov, 2020). The capability framework identifies five instrumental freedoms: political freedoms, economic facilities, social opportunities, transparency guarantees, and protective security (Sen, 1999, p.9). These real freedoms denote a real opportunity to achieve something people have a reason to value. Sen's concept of freedom is about the process and participatory justice. At the same time, he also outlines the importance of distributive justice because the goal is to ensure human well-being, even if it involves compromising certain freedoms in a particular situation. An example of functioning and capability is access to public transport. The availability of public transport in a neighborhood is a capability or real freedom that can help people in their employment, education, and access to healthcare facilities. However, if a person chooses not to use public transport despite having the option, she has not functioning which relies on public transport's capability.

Means and Ends

In political philosophy, the debate about means and ends is important because it focuses on what is the most valuable action in a situation. Is it the processes in themselves or the end that justifies the actions? Capability theory allocates significant importance to both means and ends depending on the impact regarding capabilities and functionings. The capability theory values a policy or action based on its impact on the capabilities and functionings of the people (Robeyns & Byskov, 2020). According to Robeyns (2017, p.62), the concept of means-ends:

Implies that the capability approach requires us to evaluate policies and other changes according to their impact on people's capabilities and actual functionings; yet at the same time, we need to ask whether the preconditions — the means and the enabling circumstances — for those capabilities are in place.

Although the capability approach starts by placing the end as the central point of evaluation (how a policy impacts a capability), it is also sensitive to the means. The capability approach focuses on capabilities and functionings, so capability is all about ends (Robeyns & Byskov, 2020). However, this concept of the means and ends can be understood from income and development under the capability framework. Development under the capability approach considers not just income but also means about which people care. For example, if a policy aims to increase employment in an area through technical education, providing technical education to both males and females would make a policy fair because a mere focus on male education could also bring the desired results in increasing employment. Climate policies, like emissions reduction and temperature targets, are not an end but a means to create conditions for human flourishing and development.

Conversion Factors

The idea of conversion factors suggests a relationship between a good or service and a resultant functioning. The conversion factors can help a person to transform a resource and attain a functioning. For example, a person who is healthy and can drive a car without assistance has a higher conversion factor than someone with a disability and cannot drive a car. The term 'conversion factor' refers to the ability of an individual to turn resources (goods or services) into valuable functionings (achievements or capabilities). It highlights how personal, social, and environmental factors influence one's capacity to effectively use resources to achieve well-being and desired outcomes (Robeyns & Byskov, 2020). There is a complex relationship between income and resultant substantive freedoms

because the relationship between income and achievements is not constant or straight, and different conversion factors lead to different functionings (Sen, 1999). These conversion factors are crucial in converting resources and capabilities into a functioning or real achievement.

The conversion factors can be of three types: personal, societal, and environmental. All these conversion factors, at varied levels, determine how beneficial a product can be for a person in attaining a functioning (Robeyns & Byskov, 2020). The personal conversion factors are person-specific, like sex, physical health and intelligence. The societal conversion factors include society, public policy, type of government and governance in practice. Environmental conversion factors are geography, climate change, and the environment. Each conversion factor can be crucial in converting resources and attaining desired capabilities and functionings. Each conversion factor comprises a range of elements presenting the complete existence of a conversion factor. If we take the case of environmental conversion factors, the:

Environmental conversion factors emerge from the physical or built environment in which a person lives. Among aspects of one's geographical location are climate, pollution, the likelihood of earthquakes, and the presence or absence of seas and oceans. Among aspects of the built environment are the stability of buildings, roads, and bridges, and the means of transportation and communication (Robeyns, 2017, p. 60).

If a country wants to ensure food security for its people, all three conversion factors will play a role in attaining the desired goal. First, it depends upon the people's health situation and the food requirements of everyone. Regarding environmental conversion factors, whether the country has enough cultivable land and sustained provision of fresh water. Regarding societal conversion factors, whether the right policy is in place and if the government has the requisite mechanism to attain food security. An important aspect of conversion factors is that they vary tremendously, so policies and approaches must be sensitive to different conversion factors and contexts in which they are applicable. In the case of climate change, the ability to take advantage of or successfully implement specific climate responses like adaptation, mitigation, and CGE is important.

Diversity and Human Agency

The concept of conversion factors or means and ends suggests that the capability approach is a flexible framework that appreciates diversity in roles and views. One of the critical concepts of the capability approach is the full acknowledgment of human agency and diversity, unlike other normative theories

(Robeyns & Byskov, 2020). The inherent flexibility in the capability framework allows scholars to criticize Western dominance and acknowledge the divergent views of developing countries. According to Sen:

The conviction of cultural superiority merges well with the asymmetry of political power. Winston Churchill's famous remark that the Bengal famine of 1943, which was the last famine in British India (and also the last famine in India altogether), was caused by the tendency of the natives to breed "like rabbits" belongs to this general tradition of blaming the colonial subject (Sen, 1999, p.174).

The colonial mindset blames developing countries for poverty and environmental deterioration but does not consider the harm done by the Western economies. Sen also refers to Richard Ned Lebow's observation that Britain's poverty resulted from economic activity. At the same time, in Ireland, it was attributed to the laziness of the Irish people (Sen, 1999, p.174). The capability approach highlights these double standards of the Western countries and argues that the social and economic challenges developed countries face are quite different.

Diversity leads to another idea in the capability framework: human agency and autonomy. The capability approach emphasizes human agency and acknowledges that humans should exercise free will. Sen expands the idea of freedom by discussing well-being and human agency (Robeyns & Byskov, 2020). Agency freedom acknowledges that humans have different choices and visions about their well-being, and humans living in a particular situation can determine the most viable well-being mode. For example, a person may earn more by continuing a profession like engineering, yet if she chooses to opt for music, it is her free will to determine the most suitable profession.

Nussbaum is committed to a more substantive version of human autonomy, which means that certain material conditions must be met for people to be free. It is also one of the critical differences between Martha Nussbaum and Amartya Sen. For Nussbaum, there are ten key capabilities, and that are (i) life, (ii) bodily health, (iii) bodily integrity, (iv) senses, imagination, and thought, (v) emotions, (vi) practical reason, (vii) affiliation (viii) other species (being able to live with concern for animals, plants, and the world of nature) (ix) play and (x) control over one's environment (Nussbaum, 2011, pp. 474-376). Sen is cautious in adopting a universalistic approach because he believes that many people in the global South struggle to meet the basic needs of their lives without significant support from governmental institutions. Placing the prerequisite on material conditions may not be helpful in the context of the global South. This cultural relativism potentially hinders Nussbaum's push to

universalize capabilities (Saigaran et al., 2015). This notion of cultural relativism is significant in the research and governance of SRM, which ought to be governed by a common approach at the global or regional level. Sen acknowledges the existence of different cultures and values worldwide and believes that diversity should be respected in scholarly and policy affairs. Pluralism for CGE governance is deeply problematic because it necessary subjects everyone to a single grand solution, potentially hegemonic and likely to reflect the interests of powerful states or groups.

Sustainable Environment as Meta Capability

For the capability approach, a sustainable environment can help to protect capabilities and functionings. Environmental sustainability is a meta capability because the quality of the environment in human lives is as important as shelter and food (Holland, 2008, p. 320). A sustainable environment is a prerequisite for enabling other material capabilities (Holland, 2008). Our substantive freedoms:

Will depend also on environmental conditions, including climatic circumstances, such as temperature ranges, or flooding. The environmental conditions need not be unalterable – they could be improved with communal efforts or worsened by pollution or depletion (Sen, 2009, p.255).

Climate change or climate policy should be evaluated regarding how it impacts human capabilities. The rapid melting of glaciers causes unprecedented floods, destroying crops and causing food security; this is a case of how climate change impacts capabilities. The sustainable environment concept as meta capability is like Raworth's idea of doughnut economics. Raworth presents a visual framework for sustainable development in which she envisions an "environmentally safe and socially just space for humanity to thrive in" (Raworth, 2012, p.4). Raworth balances the government's social priorities and planetary boundaries so humanity can thrive. Similarly, the capability approach treats the relationship between human beings and the environment regarding its impact on human capabilities. The value of the environment exists in what it offers to people, not just its existence or the state of nature. The capability approach sees anthropogenic climate change as a source of deprivation of human capabilities. It justifies protecting human capabilities threatened by climate change and striving for a life people can cherish and enjoy.

The value of the environment cannot be just a matter of what there is, but must also consist of the opportunities it offers to people. The impact of the environment on human lives must

be among the principal considerations in assessing the value of the environment (Sen, 2009, p.248).

The concept of well-being in the capability approach is holistic, and the mere existence of a thing or commodity is not treated as an end. Similarly, the worth of an environment exists in what it offers to human beings and not just in emission increase or decrease indicators. The thinking that the environment in its original form (natural) is best is considered flawed in the capability approach. It argues that interventions to attain and protect a sustainable environment are justified, and these interventions should not be viewed as interference in affairs of nature. According to Sen:

To take an extreme example, in understanding why the eradication of smallpox is not viewed as an impoverishment of nature (we do not tend to lament: 'the environment is poorer since the smallpox virus has disappeared'), in the way, say, the destruction of ecologically important forests would seem to be, the connection with lives in general and human lives in particular has to be taken into consideration (Sen, 2009, p.248).

Sen does not view nature or naturalness as an end; instead, we must assess interventions on what they can achieve. Sen does not grapple with the concept of risk and uncertainty, a central concern with CGE. Environmental interventions can aim to protect capabilities and functionings and ensure protective security. A "protective security is needed to provide a social safety net for preventing the affected population from being reduced to abject misery and in some cases even starvation and death" (Sen, 1999, p. 40). For example, a village farmer has been selling her grain at a better price for many years and maintaining a better livelihood, including food, housing, and education for her kids. Suddenly, due to climate change, there is massive flooding, the productivity of crops suffers, and the farmer gets less production of her crops. Besides managing flood water, the farmer and her family would have issues like food security and health, which could compromise their capabilities and function. All climate policies or interventions, namely adaptation, mitigation or CGE, merit consideration to save the capabilities of people dependent on a sustainable environment.

The capability approach questioned the feasibility of GDP and income as the sole criterion of human well-being in economics. Similarly, the capability approach does not consider it appropriate to focus on forest cover or GHG emission levels as criteria for a sustainable environment. The forest cover or groundwater table are just a few indicators and do not present the complete picture of human interaction with their environment. For example, reforestation may increase forest cover. However,

if the plantation primarily comprises non-native plants, it may hurt the local ecosystem, decomposing the native plants and releasing more carbon dioxide from the soil (Waller & Allen, 2022).

Moreover, the capability considers that humans are responsible for managing a sustainable environment for themselves, future generations, and species like animals. Sen is a great admirer of the Brundtland Commission report of 1987 because it highlighted the importance and value of the environment for all living creatures, not just humans. Sen notes that the Brundtland report does not just talk about preserving human life but also discusses intergenerational responsibility. According to Sen:

Indeed, the freedom to determine the nature of our lives is one of the valued aspects of living that we have reason to treasure. The recognition that freedom is important can also broaden the concerns and commitments we have. We could choose to use our freedom to enhance many objectives that are not part of our own lives in a narrow sense (for example, the preservation of animal species that are threatened with extinction). This is an important issue in addressing such questions as the demands of environmental responsibility and of 'sustainable development' (Sen, 2009, p.227).

This concept of intergenerational responsibility justifies allocating time and resources for futuristic climate policies to attain a sustainable environment. Our actions will affect future generations, even if we describe them as sustainable (Scholte, 2010). Some CGE debates have highlighted a similar argument about climate engineering approaches that commit future generations to maintaining CGE activities (Asayama & Hulme, 2019). Of course, the failure to do SRM research could also have the opposite effect, subjecting future generations to high levels of climate suffering because of a failure to engage with a potential set of solutions. Humans may strive to improve climatic conditions at the community level, but the environment is a given thing for an individual. Individuals have little choice or agency to alter the pre-existing environment and its impact on their capabilities.

Capability Approach and Interface with Technology

The capability framework acknowledges the importance of technology for protecting human capabilities and attaining real freedom. The "technical objects have a generative and a 'transformative' dimension through which they enable capabilities directly and affect other inputs in the attainment of valued capabilities" (Haenssger & Ariana, 2018, p. 98). Technologies like computers and the internet have economic value and impact people's social lives (Sen, 1999, p. 241). Technology

can benefit people depending on social, economic, and cultural factors (Osterlaken & Hoven, 2012). While applying the capability approach, many innovative technologies have been analyzed for their contribution to human development, especially in developing countries. There is a growing trend in developing countries to integrate modern technologies (i.e., mobile phones, solar energy panels, telemedicine, internet) into social protection programs to ensure people's well-being. One example of integrating technology to attain well-being in developing countries is designing social safety net programs through which governments make various interventions like cash transfers using mobile banking (the world bank, 2019). The United Nations Development Program (UNDP) has observed that in the 21st century, two factors will play a key role in determining a country's progression in terms of the human development index (HDI). The first is tackling the issue of climate change successfully, and the second is the countries' ability to access and adopt innovative technologies (HDR, 2019). These two factors are deeply interconnected, as addressing climate change often relies on the deployment of advanced technologies for renewable energy, sustainable agriculture, and efficient resource management. However, the effectiveness of these technologies depends not only on their availability but also on a country's capacity to adapt, implement, and scale them within its unique social, economic, and environmental context. Therefore, bridging the gap between technological advancement and practical application is essential for building resilience and achieving sustainable development goals.

Responsible technological innovation aligns with the capability framework as both approaches focus on "having reason to value." The capability approach views technology as a means whose importance is socially constructed and highly context dependent. It is an important distinguishing feature between CDR and SRM. Global SRM cannot be isolated; therefore, it requires attention to its approval and implementation conditions, which indicates that consent is critical. The UK's Engineering and Physical Science Research Council (EPSRC) has worked on responsible innovation. The broader argument of responsible innovation is that the innovation processes ought to engender a degree of legitimacy about future scenarios associated with new technologies. EPSRC has supported the idea of a desirable future to make innovation and technology acceptable in society (Owen, 2014; Stilgoe et al., 2013). Developed countries have transferred and sponsored certain technologies to developing countries (like coal power plants) without considering much about the social and environmental conditions of the host countries (Batres et al., 2021). The same issue applies to BRI, which has environmental implications for the host countries and highlights the aspect of fiduciary duty. It is necessary to

deliberate that transferring environmental harms through trade and development arrangements gives rise to obligations to address them. An example of how values differ between developed and developing countries regarding CGE is evident from the transparency aspect of CGE governance. Craik and Moore (2015) argue that transparency and public engagement should be essential for CGE's governance. However, Smith (2018) believes that mere information or scientific knowledge transparency may not be enough because of the global South's limited capabilities.

Much discussion around CGE technologies has revolved around CGE's transformative nature and the issue of control. A key point here is that technologies are not neutral, as social norms impact technologies, and technologies also shape values, but then the question is whose values they reflect. In the case of CGE, a prominent argument is that in the backdrop of climate justice, the global South should have greater control over developing these technologies to reflect developing countries' values, goals, and aspirations. CGE technologies must enhance development by acting as a conversion factor to attain or maintain the well-being of humans and other species threatened by climate change. CGE research can be designed so that countries (both developed and developing) are comfortable with the research and deployment of CGE.

Duties

A possible concern about the capability approach could be that this approach primarily focuses on rights but does not consider duties. The questions of obligations and responsibilities are central to any account of justice (Onora O'Neill, 1996). Sen has discussed duties while discussing human rights, and his approach is quite loose and practical and rooted to some degree in the obligation to consider actions that would address the capabilities of others (Sen, 2004). The most obvious argument concerning duties comes from Nussbaum, who argues that all governments worldwide must ensure their citizens enjoy specific capabilities (Nussbaum, 2017, p.185). Nussbaum does not elaborate on other actors' duties because the governments are not the only actors responsible for ensuring justice according to the capability framework. For example, multiple stakeholders are involved in the climate change issue, and all actors who can improve the situation have clear duties. Sen's ideas of fiduciary duty and intergenerational responsibility are relevant here. "A capability theory of justice may also include metaphysical commitments that extend rights and responsibilities to non-human animals and entities (Robeyns & Byskov, 2020)." The idea of fiduciary duties draws our attention to several related concepts: Who is the fiduciary? Who is the beneficiary? Moreover, what conditions trigger the duty? Is this about affected persons who control conditions over others who have duties to ensure they

account for those interests? Sen has a strongly deliberative approach that fiduciary duties are determined through practical reason and debate, which militates in favor of highly consultative and reasoned approaches. The moral aspect of duty urges rich people, national governments, and affluent communities to take responsibility, perform their moral duties, and work for the well-being of marginalized communities and species. Humans should invest time and resources as their fiduciary duty to protect less powerful creatures. This rationale also provides a normative basis for investing resources in climate policy options like CGE in the presence of adaptation and mitigation. Sen argues that:

Since we (humans) are enormously more powerful than other species, we have some responsibility towards them that links with this asymmetry of power. We can have many reasons for our conservational efforts – not all of which are parasitic on our own living standards (or need fulfilment) and some of which turn precisely on our sense of values and on our acknowledgement of our fiduciary responsibility (Sen, 2009, p.251).

This concept of fiduciary duty in the capability approach can also be a parameter for determining rights and responsibilities between rich and developing countries. The key issue is power over the conditions of others. Economic and political power differentials characterize north-south relations. The key point here is that there is a basis for developing a theory of obligation rooted in power and relevant to CGE generally and the BRI.

Limitations of the Capability Approach

A possible criticism regarding the capability approach is that it is too individualistic and provides weak conceptual grounds for evaluating groups and countries. CGE research is a multilevel consideration that must examine individuals and states, but states primarily make critical development decisions. One concern is that state decisions do not reflect individual capabilities. For example, Pakistan's decision to continue to pursue coal energy (made at the state level) appears to ignore the capabilities of future generations. Nevertheless, perhaps Sen provides a basis to critique the state's actions.

However, Robeyns (2017) outlines four reasons for justifying the suitability of the capability approach for groups and states. First, the capability approach embraces normative individualism, but this approach does not support ontological individualism. Normative individualism means social arrangements should be evaluated from the perspective of those living under those arrangements. While ontological individualism means social events are a complex reflection of individual actions.

Second, scholars within the capability framework have focused on groups rather than individuals by discussing groups like women, people with disabilities, and specific marginalized communities. Third, UNDP's annual human development and capabilities reports have focused on collective well-being. The key theoretical framework behind these development reports is also the capability approach. "The approach was initially developed as a way of looking at nations one by one and comparing them with one another" (Nussbaum, 2007, p. 22). Finally, the capability approach accepts collective social norms as important in determining technological artifacts' utility. It acknowledges that electric cars in Canada will impact functioning and capabilities differently than in Africa because of different social norms or conversion factors.

The idea is that CGE should be viewed as a form of development and CGE broadly as a freedom-enhancing (capability-enhancing) mechanism. CGE could be both a freedom and an unfreedom as climate change is a form of unfreedom. Suppose CGE is seen as development (as freedom). In that case, there is a need for the framework to analyze different applications of CGE to determine whether they will be viewed as freedoms or unfreedom (good development or bad). This may focus on the framework's purpose and give it a more evaluative bite.

The Capability Approach as an Evaluative Tool for Social and Environmental Policies

Sen's capability approach is fundamentally focused on evaluating individuals' genuine freedoms and opportunities to pursue a life they find valuable (Sen, 1999). This approach can assess CGE by examining whether CGE policies empower communities to attain essential capabilities, such as well-being, security, and development. Nussbaum's ten central capabilities provide a structured methodology for assessing whether policies support crucial aspects of human functioning, including bodily health, social affiliation, and control over one's environment (Nussbaum, 2000). By framing the capability approach regarding "freedoms" and "opportunities," we establish an important baseline for evaluating CGE proposals concerning human wellbeing. For instance, we might ask, "Does the CGE policy enhance community control over environmental outcomes?" This question, rooted in the capability approach, is an example that serves as a robust tool for assessing CGE initiatives.

The capability approach has demonstrated considerable adaptability to assess various policy domains, inspiring scholars and policymakers with its potential. Robeyns (2005) highlights the approach's function as a conceptual framework for assessing social justice, underscoring its inherent flexibility.

Deneulin (2009) further illustrates the capability approach's applicability in development policies, using well-being and agency as criteria to evaluate impacts on marginalized communities. Within social and development policy, the capability approach has emerged as an invaluable framework for assessing gender equality and poverty initiatives. For example, van Staveren (2001) and (Jain, 2020) applied the framework to evaluate gender equality policies, asserting that a narrow focus on income or employment fails to capture the comprehensive essence of gender equality. In contrast, the capability approach provides a broader perspective by examining freedoms, such as the ability to participate in society and make informed life choices. Similarly, Alkire (2002) shifted the conversation on poverty from income-based measures to multidimensional indices encompassing education, health, and social participation capabilities. This methodology has significantly influenced policy evaluations in development contexts that prioritize well-being. The capability approach has also been utilized in health policy evaluations, focusing on healthcare availability and individuals' capacity to attain health outcomes. Anand, Peter, and Sen (2004) explored how capabilities offer a more holistic health measure, extending beyond traditional medical indicators to inform health policies that enhance individuals' overall well-being. Likewise, Walker and Unterhalter (2010) employed the capability approach to assess educational policies, concentrating on whether these policies facilitate access to quality education and enable meaningful societal participation. This approach is particularly effective in addressing inequalities in educational access and outcomes, making it especially valuable for evaluating the impacts of social policy. Collectively, these studies highlight the potential of the capability approach as an evaluative framework across diverse policy contexts, inspiring its effectiveness.

In environmental governance, there are instances where the capability approach has been employed to assess and measure the impact of climate policies. Scholars such as Schlosberg (2007) and Holland (2008) have utilized this approach to explore ecological justice within environmental policy. Their research focuses on whether policies effectively protect and enhance the capabilities of affected communities, emphasizing the need for individuals to have essential resources and freedoms to live in a healthy environment and participate in ecological and social decision-making processes. Furthermore, the capability approach has been examined in relation to both distributive and procedural aspects of justice in implementing adaptation and resilience policies (Shepherd & Dissart, 2022; Cañizares-Gaztelu et al., 2024). Another important application of this approach is in evaluating sustainable development policies and their alignment with the Sustainable Development Goals (SDGs) (Klein & Ballon, 2017; Seckler & Volkert, 2021). This framework is particularly valuable in the context

of environmental justice, as it considers both human and ecological well-being and advocates for policies that safeguard capabilities for future generations. The approach assesses whether policies empower communities with the necessary resources to manage climate impacts, sustain their livelihoods, and engage in climate-related decision-making. These examples illustrate the capability approach's effectiveness in evaluating justice and well-being outcomes across various policy domains, underscoring its relevance to climate governance.

It is crucial to discuss the limitations of the capability approach in the context of climate governance. While the capability approach has demonstrated versatility across various policy domains, it faces challenges in capturing qualitative aspects such as freedom and agency, especially in large-scale or complex policy environments. Moreover, the approach's focus on individual liberties may need to be adjusted to tackle the collective and ecological concerns inherent in climate governance. Understanding these challenges and potential adjustments is key to fully engaging with the capability approach in climate governance.

The capability approach offers both flexibility and relevance for assessing CGE initiatives. This framework can be adapted to various CGE contexts by concentrating on pertinent capabilities. For example, in local environments, the focus on "Institutions/Governance" may highlight community-based governance, whereas in international contexts, it might pertain to multilateral agreements. With emphasis on well-being, freedoms, and opportunities to pursue meaningful life paths, this approach is a valuable tool for evaluating policies beyond economic outcomes. It assists policymakers in designing and assessing policies prioritizing human development and justice, making it particularly applicable to climate governance, underscoring the importance of democratic participation, equity, and long-term well-being.

This section discusses the possible application of the capability approach concerning CGE research and governance. The capability approach is a flexible framework applied in many other disciplines; therefore, its implications are broad and vary according to the context. The capability approach draws on the democratic and substantive aspects. CGE should be framed not as a solution to the global North's pollution problems but as a pathway for development and human well-being. The true impact of the CGE on development can only be ascertained through sustained research, but framing CGE in terms of its contribution to capabilities can set the right direction. Approaches like BECCS can have solid co-benefits for energy and CO₂ removal. These co-benefits of CDR approaches are an excellent incentive for developing countries

Making Climate Geoengineering Relevant: A Discursive Argument

To have climate geoengineering respond to the capability approach framework, engaging in a discursive argument that shifts the debate from a strictly technical and scientific perspective to one encompassing broader themes of social justice and human development is essential. The conversation surrounding CGE is frequently dominated by risk assessments, technical feasibility, and climate models; however, the capability approach emphasizes human impacts and ethical considerations.

A key argument for the relevance of climate geoengineering is that any geoengineering initiative should be assessed not only on its effects on global temperatures or carbon levels but also on its impact on human well-being in terms of its co-benefits and role in economic uplift (Moreno-Cruz & Smulders, 2017, Prütz et al., 2024). By applying the capability approach, we can contend that geoengineering solutions must be evaluated based on whether they enhance people's real freedoms and well-being, particularly the most marginalized and vulnerable populations. For instance, if an SRM technique succeeds in lowering temperatures but leads to detrimental changes in rainfall patterns that jeopardize agriculture in the global South, this would not merely represent a technical failure; it would also violate those communities' capabilities to attain well-being.

Moreover, CGE initiatives should not be viewed as mere technological solutions. Instead, CGE must be grounded in an ethical framework that promotes equitable outcomes (Pamplany et al., 2020). This encompasses the fair distribution of benefits and burdens and the inclusion of diverse perspectives, particularly those from the global South, in the decision-making process. The capability approach allows us to frame geoengineering as a matter of global justice. Geoengineering mustn't exacerbate the very inequalities that climate change threatens to intensify. By employing the capability approach, we can advocate for global governance models prioritizing justice, ensuring no region or population faces disproportionate effects from geoengineering interventions.

An important aspect in this regard is that CGE impacts cannot be protected and are highly variable. Some of these new arguments could be broader and need to engage more with the actual realities of CGE. The capability approach emphasizes the significance of protective security, highlighting the necessity of safeguarding individuals from risks and shocks that jeopardize their well-being. This framework is a compelling argument for exercising caution and establishing robust governance structures around climate geoengineering initiatives (Gupta et al., 2020). One can advocate that CGE initiatives should prioritize short-term climate mitigation objectives and the enduring protection of

people's livelihoods, ecosystems, and cultural heritage. Additionally, protective security involves implementing social safety nets for communities that geoengineering interventions may adversely impact.

CGE, as a climate policy option, needs to address the issue of agency and participation in the environmental governance decision-making processes. The capability approach's focus on agency and participation provides a robust foundation for advocating CGE initiatives that should be conducted democratically and transparently. Given geoengineering's global scale and potential consequences, it should not be managed solely by technocrats or scientists. Those most affected by these interventions, particularly in the global South, must have a significant voice in shaping these technologies (Winickoff et al., 2015). CGE, as a climate policy option, needs to promote more inclusive and participatory governance models that empower local communities to exercise their agency in determining how or whether geoengineering efforts should be implemented in their regions.

The capability approach presents a distinctive and valuable perspective for conceptualizing and assessing climate geoengineering in this scenario. It shifts the emphasis from purely technological and economic metrics to a broader, more inclusive understanding of development that prioritizes human well-being, justice, and freedom. By highlighting the importance of equity, agency, and protective security, the capability approach offers a discursive framework that evaluates geoengineering initiatives on their technical success and their potential to enhance human capabilities and contribute to a more just and sustainable world.

The ability of the states and individuals to have the freedom to consider and pursue development preferences, which may include CDR or SRM, is also valuable in terms of procedural justice. CDR derives its support from the existing global environmental governance from the Paris Agreement. The global SRM research, if banned as argued by the non-use agreement as a prior decision, can deprive the global South of its freedom to choose about the future of SRM freely. Sen places a condition here while articulating the argument about free agency that decision-makers should be able to make informed decisions with adequate knowledge of the subject matter. It provides a solid basis for enhancing developing countries' capacity and knowledge to address issues, assess risks, and devise local governance models considering those risks.

Capability-based Framework for a Just CGE

A critical question regarding CGE research and governance is how it addresses climate justice issues. The appropriate integration of climate justice in CGE research can help to understand questions related to the distribution impacts of SRM and the subsequent management of risks. As framed in the capability approach, the means and ends are both critical, and the context in which they are considered is also important. Sen's capability approach provides a sound basis upon which CGE governance can be analyzed because the capability approach addresses the issues of sustainability while keeping intact the development and justice aspects crucial for the global South. The elements of the capability framework devised here can be usefully employed in case studies of CDR, global SRM, and targeted geoengineering to address crucial ethical and governance questions. This framework can help to structure the governance model for CGE and evaluate its impact on the stakeholders. The multidimensional aspect of the capability approach helps to structure this model to cater to the needs and expectations of developing countries in global environmental governance. There are four key elements of the framework, namely, objective, processes, governance, and outcome. Each element is further categorized in the light of the capability approach.

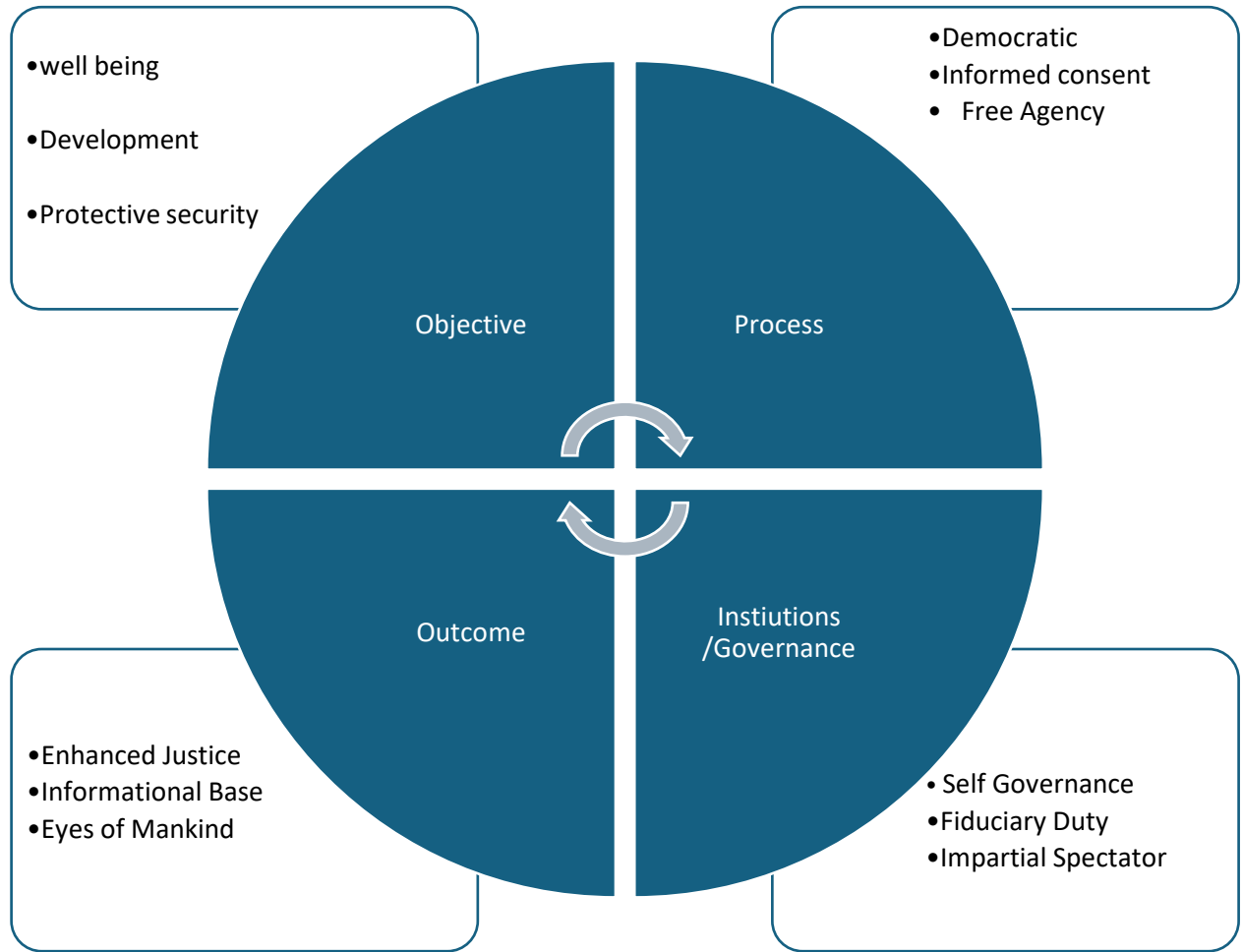


Figure 4: A Capability-based Framework for Just CGE

Sen's capability approach is fundamentally concerned with assessing individuals' "real freedoms" and opportunities to pursue a life they value (Sen, 1999). This framework can be applied to evaluate CGE by examining whether policies empower communities to achieve essential capabilities, such as well-being, security, and development. Nussbaum's ten central capabilities offer a structured method for evaluating whether policies support critical aspects of human functioning, such as bodily health, social affiliation, and control over one's environment (Nussbaum, 2000). Framing the capability approach in terms of "freedoms" and "opportunities" establishes a vital baseline for evaluating CGE proposals. For example, we can ask, "Does the CGE policy enhance community control over environmental outcomes?"—a question rooted in this approach, which serves as a robust tool for assessing CGE initiatives.

The capability approach has already demonstrated adaptability across various policy domains, supporting its relevance to CGE. Robeyns (2005) emphasizes the approach's role as a conceptual framework for evaluating social justice, highlighting its inherent flexibility. Deneulin and Shahani (2009) illustrate the capability approach's applicability in development policies by using well-being and agency as criteria to evaluate the impact on marginalized communities. These studies underscore the approach's potential as an evaluative framework across diverse policy contexts.

In social and development policy, the capability approach has emerged as a valuable framework for evaluating gender equality and poverty initiatives. For instance, van Staveren (2001) applied the approach to assess gender equality policies, emphasizing that a narrow focus on income or employment fails to capture the true essence of gender equality. Instead, the capability framework offers a comprehensive perspective by examining freedoms, such as the ability to participate in society and make informed choices about one's life. Similarly, Alkire (2002) shifted the discourse on poverty from income-based measures to multidimensional indices that account for education, health, and social participation capabilities. This approach has significantly influenced policy evaluations in development contexts where well-being is prioritized.

The capability approach has also been applied in health policy evaluations, assessing healthcare availability and individuals' capacity to achieve healthy outcomes. Anand, Peter, and Sen (2005) explored how capabilities offer a more holistic health measure, extending beyond traditional medical indicators to guide health policies that support individuals' overall well-being. Likewise, Walker and Unterhalter (2007) utilized the capability approach to evaluate educational policies, focusing on whether these policies promote access to quality education and enable meaningful participation in society. This approach helps address educational access and outcomes inequalities, making it particularly useful for evaluating social policy impacts.

Scholars such as Schlosberg (2007) and Holland (2008) have employed the capability approach to explore ecological justice within environmental policy. Their work assesses whether policies safeguard and enhance the capabilities of affected communities, determining if individuals have the necessary resources and freedoms to live in a healthy environment and participate in ecological and social decision-making. The capability approach proves valuable in environmental justice by considering both human and ecological well-being and advocating for policies that preserve capabilities for future generations. Although its application in climate governance is relatively nascent, researchers like Ballet, Dubois, and Mahieu (2007) have investigated how the capability approach can inform climate

policy. They assess whether policies equip communities with resources to manage climate impacts, sustain livelihoods, and engage in climate-related decision-making. These examples demonstrate the capability approach's effectiveness in evaluating justice and well-being outcomes in various policy areas, reinforcing its applicability to climate governance.

Addressing the limitations of applying the capability approach to climate governance demonstrates an understanding of its scope and relevance. While the capability approach has proven flexible across policy domains, it does face challenges, such as capturing qualitative aspects like freedom and agency, especially in large-scale or complex policies. Additionally, the approach's focus on individual liberties may need adaptation to address collective and ecological issues in climate governance.

The capability approach demonstrates flexibility and relevance for evaluating CGE initiatives. The framework can be tailored to different CGE contexts by focusing on relevant capabilities. For instance, in local contexts, "Institutions/Governance" might emphasize community-based governance, while in international settings, it may refer to multilateral agreements. The approach's focus on well-being, freedoms, and opportunities to pursue valuable life paths makes it a valuable framework for evaluating policies beyond economic outcomes. It guides policymakers in designing and assessing policies centered on human development and justice, making it especially relevant for climate governance as it emphasizes democratic participation, equity, and long-term well-being.

Objective

Some key questions related to any CGE initiative regarding its objectives that deserve attention are: Does CGE improve the well-being of individuals and groups? Who benefits from CGE? Does CGE address minimal levels of capabilities and protective security? The capability framework analyzes CGE as a well-being resource, not mere technological interventions to reduce emissions. The capability approach can guide determining the normative basis of the CGE research and governance. "The openness of Sen's approach, which is embodied in the notion of freedom, endorses the idea that we must not rigidly fix one way of dealing with nature" (Scholte, 2010, p. 302). According to the capability approach, the primary objective of the CGE initiative must be to attain well-being rather than limiting the CGE to carbon emissions scenarios. The environment's well-being in the capability approach is not static; it has intergenerational implications. Environmental sustainability is connected to "the substantive freedoms and capabilities of people today 'without compromising the capability of future generations' to have similar – or more – freedom" (Sen, 2009, p. 251). Sen argues for going beyond traditional statistical concepts of development, yet he refrains from taking any extreme position to

frame humans as extremely moral or immoral creatures (Sen, 1999, p.280). Sen's observation about famine and its impact on human lives is relevant to determining the normative basis of CGE research. "We still have to go beyond the output statistics to explain why it is that some parts of the population get wiped out, while the rest do just fine. Famines survive by divide-and-rule" (Sen, 1999, p.167). Multiple factors contribute to natural calamities, like lack of employment, poor purchasing power, and a rise in demand for food grains (Sen, 2009, p. 340). Climate change is one of those factors that can diminish human capabilities; therefore, CGE, as a climate policy option, needs to be analyzed to protect human capabilities in the wake of natural calamities.

The concept of protective security is quite broad, and almost anything that can help people avoid abject poverty, whether income or scientific intervention, falls in the category of protective security. Protective security includes fixed institutional arrangements such as unemployment benefits, statutory income supplements for the indigent, and ad-hoc arrangements such as famine relief or emergency public employment to generate income for the destitute (Sen, 1999, p.40). The capability approach can help to analyze CGE research regarding its impact on human capabilities and determine if a CGE program will positively or negatively impact human capabilities. The capability approach stands with people on the edge of vulnerability and determines if any change in material conditions can deprive them of their capabilities and functionings. Climate change's impact on vulnerable communities suggests they may need intervention, but the local people should determine the most feasible policy or action. The capability approach supports this process by encouraging democratic and informed decision-making.

Climate change hurts development, which is unfreedom, and CGE can be analyzed as a resource to protect or enhance development, which is freedom. There is a relationship between many CGE techniques and key development activities, such as land use, agriculture, food, water, and human rights. There are indications that large-scale CDR initiatives can significantly impact land use (Craik & Burn, 2016; Honeger et al., 2018), which may have implications for food security and human rights in the global South, as many developing countries are heavily dependent on agriculture as a key source of economy. The lack of infrastructure (i.e., energy projects, roads) in developing countries means more people living below the poverty line and being deprived of basic facilities like health and education. Government institutions in developing countries are not resourceful enough to readily provide social and financial assistance to all people below the poverty line. Therefore, many developing countries' feasible course of action is to continue their economic and infrastructure

development momentum and ensure financial opportunities for their population. Developing countries have an uphill task that they must maintain a pace of development to avoid poverty while also managing challenges associated with climate change. Climate change is undermining development, especially in developing countries, by impacting the lives and livelihoods of the people. CDR has already been included in some economic models to create financial leverage by reducing the cost of mitigation and spending more money on SDGs (Honegger et al., 2018). “Climate change poses a major threat to long-term development objectives, especially poverty reduction” (World Bank, 2022).” The capability approach enables people to achieve a life they can cherish, and development should address issues that are the cause or source of deprivation and destitution (Sen, 1999, p.186). Sen argues that:

Development has to be more concerned with enhancing the lives we lead and the freedoms we enjoy. Expanding the freedoms that we have reason to value not only makes our lives richer and more unfettered, but also allows us to be fuller social persons, exercising our own volitions and interacting with—and influencing—the world in which we live (Sen, 1999, pp.14-15).

In this respect, the capability approach places significant importance on education, health facilities, and a sustainable environment to attain a prosperous life. The capability approach wants to expand people’s freedom by reducing poverty and ensuring capabilities (Alkire, 2005). The capability approach has redefined the concept of development. Instead of focusing on GDP or GNP, it has linked development with the freedom of people to live a life they have reason to value. Sen argues that development is a multidimensional concept and restricting it to GDP limits development's accurate meaning and compromises human freedom. The capability approach is against a development program that makes humans passive rather than appreciates an active role of humans, which can positively affect humans and around them (Sen, 1999, pp. 11-12). Sen believes that:

Even though many human activities that accompany the process of development may have destructive consequences (and this is very important to understand and to address), it is also within human power to enhance and improve the environment in which we live. Indeed, our power to intervene, with reason and effectiveness, can be substantially enhanced by the process of development itself (Sen, 2009, p. 249).

Development is primarily a constructive term related to empowering people, and it should not be merely seen as an environmentally destructive activity. Human agency in pursuance of development

that brings substantive freedom can also be seen as satisfying a fiduciary duty towards current and future generations.

Processes

In this framework, the process is a key concept under which the stakeholders deliberate crucial decisions regarding CGE research and governance. Whereas governance in this framework refers to the more formal architecture of national and international policy creation, the process requires us to consider the conditions of that deliberation. For example, what measures or steps are essential to making the deliberation regarding CGE open, transparent, and inclusive? How can the democratic spirit safeguard the interests of the local communities? An example in this regard is the processes of NDC submission under the Paris Agreement. NDC was a process stage in which countries deliberated to present their emission reduction goals. At the same time, signing the Paris Agreement was a culmination when actual governance of an initiative began. Applying the capability approach in CGE governance can make decision-making more democratic and participatory. It can allow marginalized communities to raise their voice and deliberate about the governance of CGE and determine its positive or negative impact on their capabilities. The capability approach's flexibility gives it an advantage over other approaches as it can simultaneously consider various concerns that other approaches cannot (Sen, 1999, p. 86). This flexibility of the capability framework primarily stems from its ability to focus on instruments other than income while analyzing public policy (Sen, 1999). The most significant challenges to humanity can be dealt with by a democratic spirit in decision-making. Sen believes that no country has ever experienced famine where there is flourishing democracy because the policymakers and leaders must be responsive to the public pulse. Sen's idea of democracy has three main pillars: acknowledging diversity and local values as local values and divergent views are sometimes crucial and inherent in any culture for understanding the context of issues (Sen, 1999, p.247). A critical point here is that Sen appears to view values and interests as not being fixed but rather subject to change based on practical reasoning. Second is public reasoning and discourse in pursuing social justice. The public discourse is critical for acknowledging prevailing injustices and structuring new social values by people impacted by these decisions, not just those who capture elite positions (Sen, 1999, p. 287). Finally, the instrument of free agency is vital for attaining development. By placing human agency as a central theme, the capability approach treats the human being responsible for the acts of omission and commission rather than mere spectators (Sen, 1999). Sen

sees humans as agents who can design their destiny provided they have adequate social and economic opportunities.

Regarding CGE governance, the role of all three elements discussed by Sen for ensuring democratic participation is crucial. First, acknowledging local values can help policymakers customize a CGE research program and embrace diversity. The scale issue is critical as to who decides at what scale is critical for CDR and SRM. Public reasoning is crucial to accommodate the concerns of the local people and ensure the legitimacy of the CGE research program. Public reasoning requires justifying decisions in light of shared principles, which suggests the need to develop and draw on shared principles for CGE. This process is well underway with initiatives such as the Oxford Principles and Asilomar Principles. However, the CGE discourse needs to be informed, and all stakeholders must have sufficient knowledge and capacity to deliberate about the CGE governance. Informed debate is crucial as it goes into the conditions under which these debates may occur, including being informed by trusted science (as opposed to a moratorium on science). The idea is that conditions and resources should enlighten the discussion and make decisions more informed because they can significantly shape the policy (Sen, 1999, pp. 280-281). “Since participation requires knowledge and basic educational skills, denying the opportunity of schooling to any group—say, female children—is immediately contrary to the basic conditions of participatory freedom” (Sen, 1999, pp. 32-33). For informed participation in CGE research, developing countries need more knowledge about CGE to decide CGE's future in their national climate policies. The capability approach treats capacity building as a conversion factor. It strongly indicates the need for early engagement of the global south in CGE discussions.

For CGE research and governance, these democratic values enunciated by Sen are of great importance because they lay the foundation of the governance framework in which all stakeholders have an opportunity to freely express themselves and choose a path that they consider feasible. This pluralistic and democratic spirit of the capability framework aligns with the bottom-up spirit of the Paris Agreement and its instrument of NDCs and global stock take. The capability approach appreciates a "bottom-up nature that requires participation and involvement of those people who are the agents of development change” (Comim et al., 2014, p.160). Any approach to CGE governance is likely more acceptable for developing countries if it aligns with the Paris Agreement. It is tied to Sen's idea of public reasoning, which suggests that reason-giving must reference shared values or goals. The

Paris Agreement and other international conventions provide a universal basis for a shared normative vision for climate change and interventions.

The more significant opportunity for the global South in shaping the CGE research and governance can address critical ethical questions like who will be responsible if something goes wrong or who can participate in the CGE discourse. The element of free agency, the ultimate decision to pursue or not to pursue the CGE research program, and how to design its governance should be decided by states, and there should be no compulsion in this regard. This goes to the issue of consent, which is key for SRM. Sen would have a lot of difficulty with other states (powerful) deciding on using SRM that could impact smaller weaker states as it removes agency for a meta capability. The only caveat in this regard is that in the case of global SRM, states need to exercise restraint and caution, and any research or deployment should be democratically processed at the global or regional level to avoid pitfalls if something goes wrong. The capability approach favors open discussion, democratic decision-making, and involving all those likely to be impacted by the decision.

Institutions/Governance

The Institution stage addresses some key questions: Who is responsible for what? Moreover, in an adverse situation, who is responsible for acting as fiduciary? A possible area of application of the capability approach regarding CGE is to envision the governance for CGE. CGE governance means an overarching policy to manage climate change and related risks beyond the scope of adaptation and mitigation while simultaneously addressing the risks associated with CGE (Parson, 2017, p. 5). The existence of governance institutions ensures that the stakeholders have common codes of behavior and that each party can trust another party (Sen, 1999, p. 265). Government institutions should enhance justice; creating institutions is not an end (Sen, 2009, p.82). The capability approach questions traditional approaches of governance in which ethics and equity have got less attention. Even though Integrated Assessment Models (IAMs) are helpful in climate policymaking, they alone do not reflect equity in decision-making (Batres et al., 2021). In designing and implementing technological projects like CDR, environmental justice should be at the center of decision-making (Batres et al., 2021). The governance of CGE involves embracing changes that can significantly transform human lives over many years. A point may come when anthropogenic climate change becomes such a big issue that humans may have to consider large-scale environmental intervention. CGE research, especially SRM, will change human lives unprecedentedly; therefore, designing the governance of CGE can be the best tool in our hands to absorb the shocks of change. CGE governance

must be assessed from the global South's perspective and through a justice lens, given the origins of climate change and its implications for the global South. Sen acknowledges that change is a naturally recurring phenomenon:

If a traditional way of life has to be sacrificed to escape grinding poverty or minuscule longevity (as many traditional societies have had for thousands of years), then it is the people directly involved who must have the opportunity to participate in deciding what should be chosen (Sen, 1999, p. 31).

CGE governance needs to be sensitive to both means and ends. There are some crucial questions about the role and objectives of CGE and how to approach the risks inherent to CGE and structure obligations. Managing finance is an important issue regarding CGE governance, especially for developing countries historically looking toward developed countries for adaptation and mitigation efforts. The question is, "Who will pay the least developed countries to implement territorial CE?" (Humphrey, 2011, p. 113). This is one of the key questions for the role of fiduciary duty under CGE governance. It could be one of the most contentious issues of CGE governance. For some scholars, the answer to financing CGE research in developing countries exists in international public finance through development institutions or a global support fund (Buck, 2012 & Humphreys, 2011). Humphrey and Buck have focused on multilateral agencies like the World Bank and IMF. However, applying the capability approach to CGE research suggests that developed countries sponsoring countries of transnational development projects like China for the BRI and their institutions should assist developing countries. From the capability perspective, financing CGE in developing countries is like providing economic facilities to protect specific capabilities threatened by climate change. Developed countries' fiduciary duty is to help developing countries tackle climate change. The concept of fiduciary obligations arises from the vulnerability of one party to discretionary decisions by another. Sen argues that:

Further, there is no need to presume a world government, or even to invoke a hypothetical global social contract. The 'imperfect obligations' associated with the recognition of these human rights can be seen as falling broadly on anyone who is in a position to help (Sen, 2009, p. 144)

Big economies can help developing countries regarding CGE research as they benefit from developing countries' human and natural resources. Article 9 of the Paris Agreement explicitly states that

developed countries shall provide financial assistance to developing countries regarding adaptation and mitigation. The parties to the Paris Agreement may extend the scope of Article 9 to fund research on CGE in developing countries.

A significant concern concerning CGE governance is who will be responsible if something goes wrong and who will pay the damages. In addition, issues like accountability, transparency and liability are very delicate concerning CGE governance. Sen supports the idea of accountability and makes it an integral part of the capability framework (Sen, 2009, p.19). In terms of transparency, the capability approach acknowledges the role and importance of transparency in social interactions. Transparency is one of the instrumental freedoms as interactions in the social environment occur on a basic level of trust. Instrumental freedom is violated if that trust is violated (Sen, 1999, pp. 39-40). The capability approach suggests a broader solution for issues concerning CGE governance. Sen cites Adam Smith's idea of an "impartial spectator" to deal with moral and political issues in a transnational world (Sen, 2009, p. 44). An impartial spectator is like an independent institution at the global level that can monitor and hold accountable countries concerning CGE research and governance.

Outcome

The key question is to determine what advantages or disadvantages have been attained from the CGE initiative and other the initiative protected human capabilities or further undermined them. How to measure those results and who will be the final authority? Capability-driven CGE research can enhance climate justice as the strong argument of any justice theory is to challenge the existing unfair situation. The global South is not benefiting from developed countries' economic activities; instead, many developing countries unfairly bear the harmful effects of anthropogenic climate change. This pattern is unjust, and any climate policy should aim to improve developing nations' capability to manage the harmful effects of climate change through adaptation, mitigation, or CGE. A justice-based framework "serves as the basis of practical reasoning (and) must include ways of judging how to reduce injustice and advance justice, rather than aiming only at the characterization of perfectly just societies" (Sen, 2009, p. ix). The capability approach signifies the importance of distributional and participatory aspects of justice. The concept of justice in the capability approach "insists that justice should not focus solely on distributive ideals, but instead, on the range of capacities necessary for people to develop free and productive lives they design for themselves" (Schlosberg, 2012, p. 452).

The critical question is how CGE research can reduce climate injustices. The capability approach argues that there is a plurality of reasons to pursue justice, and each is significant; however, the reach of

public policy can change with the change in the informational base of a justice theory (Sen, 1999). Issues like famine and poverty exacerbated by climate change will have a different information base than those who argue for GDP and GNP as a measure of poverty reduction. Therefore, approaching climate policies, like CGE, through a capability framework will have a different information basis. An information base about human well-being will likely support more research on CDR and SRM and find ways to curtail human miseries in the wake of climate change. However, there is an apprehension that CGE deployment can create an unjust scenario known as a moral hazard argument. The moral hazard argument suggests that pursuing CGE as a climate policy option will undermine the existing climate policy options: adaptation, mitigation, and compromise emission reduction goals set in the Paris Agreement. The capability approach helps us to deal with the moral hazard scenario, as Sen argues:

The justification here takes the form of arguing that if some action that can be freely undertaken is open to a person (thereby making it feasible) and if the person assesses that the undertaking of that action will create a more just situation in the world (thereby making it justice-enhancing), then that is argument enough for the person to consider seriously what he or she should do in view of these recognitions (Sen, P.206, 2009).

Governments can take specific remedial measures to avoid risks and adopt a participatory approach by placing people's well-being at the center. Sen also places a system of checks and balances and argues that actions should be judged through the “eyes of mankind” instead of personal moral justifications (Sen, 2009, p. 130). Any action taken by states should be cognizant and empathize with other communities' conditions and viewpoints while making a particular decision. It means that while designing the CGE research and governance framework, policymakers should look from the eyes of mankind and not just from the eyes of a particular community or nation. The goal of any climate policy option, including CGE, is to ensure human well-being while ensuring environmental sustainability.

Conclusion

I have argued for reframing CGE as just development, positioning it to address climate and developmental challenges simultaneously. Using Amartya Sen's Capability Approach, CGE can be reimagined as a justice-oriented climate policy option that enhances freedoms and opportunities for communities, particularly in the global South. This perspective shifts the narrative from CGE as a technical fix to a transformative solution capable of addressing systemic vulnerabilities, promoting equity, and fostering sustainable growth.

Chapters 3 and 4 explore practical case studies to demonstrate the application of this framework. Chapter 3 investigates low-carbon development through CDR in Pakistan under China's BRI, showcasing how CGE can align with national development goals. Chapter 4 examines targeted geoengineering for glacier protection in South Asia, highlighting region-specific applications of the framework. These examples underscore the potential of CGE as a just development, ensuring that climate interventions are inclusive, equitable, and transformative in addressing the dual imperatives of justice and sustainability.

The first key question I try to answer in this chapter is: Can CGE be reframed as development, and how does that affect our understanding of CGE as a climate policy option? Altering our sense of the objectives of CGE as development suggests that CGE must be designed to benefit the global South as climate change most affects their capabilities. The objective of CGE is not to address climate change per se but rather to address how climate impacts capabilities, and this may reorient CGE from simply thinking about climate outcomes to thinking about other benefits and needs of developing countries; very often, the more immediate needs (protective security).

This discussion goes over the second key question, which is about the engagement of the global South in CGE debates. Why should the global South engage in this? Focusing on capabilities provides a clearer answer that relies less on global solidarity (than the Paris Agreement) and more on achieving and realizing improved conditions and capabilities. The focus on agency provides greater scope for engagement if genuine as it does not involve a loss of control, which is one of the global South's concerns with CGE.

Third, scale emerges as a crucial factor when considering the process implications. The decision-making processes need to align with the scale of impact and consider diverse perspectives. This suggests that CDR may be more feasible or compatible with Senian ethics, as it allows for greater involvement of state communities. On the other hand, SRM is highly uncertain and potentially hegemonic. However, states have the right to evaluate and decide whether SRM is a feasible solution and the scale at which it could be implemented (targeted or global), which requires further research. This is undoubtedly complex, but developed countries, due to their control over these technologies and due to their potential impact on the global South, global North owe a fiduciary duty to the people of the global South. The investment flow from the global North to the global South impacts climate conditions.

This chapter examined the discussion of CGE research and governance relevant to developing countries by applying the capability approach. This article argued that the capability approach provides an alternative framework to analyze the research and governance of CGE. Applying the capability approach in many other disciplines and policy areas like information technology, health, education, and human development provides a rationale for its application and operationalization in climate change and CGE. The capability approach's justice and well-being aspect provides a starting point for CGE research. It is true that many human activities adversely affect the natural environment, but humans can also develop activities that benefit the natural environment. Human's passive role is not always an ideal move to preserve or protect the environment. Because of various governance and technical challenges, CGE, especially SRM, may not be fully deployed even after a few years or decades of research. However, some developing countries' environmental vulnerability is imminent, and the capabilities and functions of their inhabitants are threatened by climate change. Climate change negatively affects human capabilities, and an intervention intending to protect human capabilities seems appropriate according to the capability framework. However, some essential prerequisites for CGE operationalization under the capability framework include scientific evidence availability and democratic decision-making processes.

Any country or entity should not pursue CGE research to evade their carbon emission commitments under the Paris Agreement. Using CGE to evade emission reduction responsibilities committed under the Paris Agreement will violate compliance and deliberative processes agreed upon by the parties to the Paris Agreement. All climate policies, including CGE, must aim for human well-being, save communities from droughts, floods, or heat waves, and contribute to sustainable environment and development. Climate interventions can be analyzed as protective security measures for highly vulnerable populations due to climate change. CGE research for developing countries must be evaluated as part of a social and climate safety net. CGE can be researched along with adaptation and mitigation to avoid climate-induced disasters and related economic pitfalls for the already poor population. CGE research needs to be designed to protect people from the harmful impacts of climate change and ensure people's well-being through targeted interventions like preserving the Arctic or the Himalayas. It is like creating a climate safety net for highly vulnerable people who face existential risks due to anthropogenic climate change. Given the interdisciplinary nature of the capability approach, this article is not an exhaustive effort, and many areas can be analyzed regarding CGE research and governance using the capability approach.

In the case of South Asia, two scenarios suggest that analyzing CGE research from a development perspective merits consideration. Developing countries may like to investigate CDR as a climate policy option to honor their emission reduction commitments under the Paris Agreement while installing new energy and infrastructure projects. Developing countries receive significant investments through economic and trade partnerships from China, the European Union (EU), and the USA. These investments are usually meant for construction and industrial activities, and resultant emissions may compromise the emission reduction goals of host developing countries under the Paris Agreement. One example is China's BRI, a potential source of significant emissions in developing countries (Hilton, 2019; Ivleva, 2021). Under the BRI, China has exported its coal power plants to many developing countries facing energy shortages. China provides financial and technical assistance to partner countries of the BRI to install these coal-fired power plants. Coal power plants are detrimental to the environment but provide a quick solution to the energy crisis in developing countries like Pakistan. Developed countries term these coal-fired power plants as sources of emission and pollution increase in developing countries. However, from a developing country's perspective, energy scarcity leads to energy poverty and hurts the capabilities of hundreds and millions of people in Asia and Africa (Gates, 2021). The complexity of the situation is that:

it's hard to stay healthy if your local medical clinic can't keep vaccines cold because the refrigerators don't work. It's hard to be productive if you don't have lights to read by. And it's impossible to build an economy where everyone has job opportunities if you do not have massive amounts of reliable, affordable electricity for offices, factories, and call centers (Gates, 2021, p.4).

Continuous energy is essential for many developing countries to keep their economies functioning. Ideally, this energy should come from renewable and clean energy resources, but this is not the case, given their limited financial and technical resources. When developing countries rely on Chinese assistance for coal power plants or pursue substantial infrastructure projects, options like CDR to remove emissions become relevant.

Second, is a case of targeted climate intervention to protect or slow down the rapid melting of glaciers in the HKHK region. Some scientists have proposed refreezing the Arctic through targeted interventions that may protect a global climate tipping point (Moore, 2020; Bodansky & Hunt, 2020). Restricting global sea level increases by refreezing the Arctic is an attractive consideration for many coastal cities (Cooke, 2019). Protecting the local glaciers through targeted interventions would be

crucial for many South Asian countries, like India, Pakistan, and Nepal. The existence and preservation of glaciers in the HKHK region is essential for millions of people in South Asia because these people depend on these glaciers for water to use in the energy and Agriculture sectors (Mani, 2021). The countries in South Asia, with vast mountain ranges and glaciers, face a threat to their glaciers because of the increase in global average temperature. The rapid glacier melting can trigger “glacial lake outburst flood (GLOF) (that) is a phrase used to describe a sudden release of a significant amount of water retained in a glacial lake, irrespective of the cause” (Emmer, 2017, p. 1). The GLOF can cause a significant threat to the life and property of the people. Concerning artificial glacier interventions, there are few initiatives from local people and authorities trying to slow down the rapid melting of glaciers. For example, in China, some regions use the glacier-wrapping technique, which covers some glaciers with a 5-8 mm thick geotextile cloth to prevent rapid melting (Zizhu, 2020). It is unlikely that adaptation and mitigation alone will suffice in the short run to avert disasters and protect people's lives in glacier regions.

Chapter 3: Low-carbon Development Through Carbon Dioxide Removal (CDR) in Pakistan Under China's Belt and Road Initiative (BRI)

Introduction

This chapter is a case study on “CDR as development,” focusing on the BRI, a transnational development project sponsored by China in developing countries like Pakistan. The decision to look at the BRI is influenced by the significant climate impacts of the BRI, which are a source of international criticism for China. Therefore, greening the BRI is a major issue. Still, it may be hard to green the BRI through emission reductions alone (since that may negatively affect the development aspirations of both China and its partner countries). This chapter looks at whether CDR provides an avenue for greening the BRI and whether certain aspects of the BRI make ‘just CDR’ feasible. There is growing evidence that global efforts to curtail carbon dioxide emissions through reductions alone are insufficient to meet the Paris Agreement's temperature targets. Therefore, “it is no longer sufficient to reduce emissions alone — CO₂ will also need to be removed from the atmosphere, on a scale never previously attempted” (Mace et al., 2021, p.3). Removing emissions can have governance and ethical implications in the countries that host CDR initiatives.

Looking at the BRI can inform us about development and the institutionalization of development, which indicates a more modern form of development and captures complexity with increasing emissions, leading to necessary but harmful developments. Development under the BRI is structured as a relationship of partner countries and marks a shift away from an aid or conditionality-based model. This transnational development model case study of the BRI also signifies the rise of the south-south collaboration within global governance. A BRI led by China is predominantly a project of the global South and highlights many aspects of the climate justice movement advocated by developing countries. This case study also helps to understand whether the BRI's governance framework gives the host countries a voice.

Developing countries might consider alternative options like CDR and the existing mitigation policy to achieve emission reduction goals while participating in transnational development projects like the

BRI. The case study of BRI can help to understand the relevance of CDR as a climate policy option in the host countries of the BRI, which otherwise look towards developed countries' support to execute projects related to mitigation and do not consider mitigation as their top priority. Understanding and analyzing how host countries (of the BRI) can accomplish the carbon emission reduction goal while simultaneously engaging in carbon-intensive development activities is important (Fan et al., 2019). Developing countries like Pakistan have a challenging situation as they must address issues like poverty, energy scarcity, and infrastructure requirements while maintaining their emission reduction goals under the Paris Agreement with minimal resources.

The central objective of this chapter is to examine CDR as a development pathway that must be understood to address capabilities under threat due to climate change. The BRI is South Asia and Pakistan's most significant development initiative but compromises host states' capabilities by promoting GHG-intensive development. In this sense, the BRI potentially results in the ongoing loss of freedom by reducing choices and options through increasing climate risks and placing pressure on Pakistan to reduce emissions. Can the BRI be a platform for more than just infrastructure development and enhance the capabilities of the host countries by removing emissions? Can we view the BRI arrangement through the capability framework's objectives, process, institutions, and outcomes elements? The literature on the greening of the BRI has looked at the capacity of the BRI to be structured to address low-carbon development. However, it has ignored the capacity of the BRI to promote and implement CDR. Given the role CDR is expected to play in carbon reduction and removal, it is critical to consider how major development initiatives like the BRI can support CDR in the host countries.

To this end, I draw on Amartya Sen's idea of development under the capability theory and how it relates to CDR as development. Human development involves various aspects, such as economic growth and environmental sustainability. CDR can (and ought) to be reframed as a form of development while considering the case of developing countries. Amartya Sen's approach to development (focused on capabilities) is morally supportable and politically desirable in this scenario. CDR's analysis as a climate policy option from the perspective of the global South deserves attention as the global South has the most to lose or win in efforts against climate change (Sovacool, 2023). The broader concerns about CDR initiatives, like food and energy security, are most evident in developing countries (Sovacool, 2023). There is a difference between the global North and the global South in understanding and approaching various global environmental governance issues. For example, justice

has different meanings and implications in the global North and the global South while discussing issues and governance concerning CDR (Sovacool, 2023). Sen's capability approach can help to understand CDR's relevance as development in the global South. The idea of CGE (CDR) as a development is critically important. It must be emphasized and contrasted with much of the literature that treats CGE (CDR) strictly as an environmental response. The problem is that developing countries feel little attachment to emission reduction goals as they perceive it as solving a problem created by others (global North), whereas framing CDR as development shifts the focus towards implementing CDR in ways that can support the well-being and capabilities of developing countries (Sovacool, 2021; Batres et al., 2021). The connotation of CDR's dual role in addressing climate change and supporting economic development is vital for the global South.

Almost all climate policy options have a global North-south dimension. Many developing countries usually hold developed countries responsible for GHG emissions and restrict their climate actions to adaptation and disaster management instead of pursuing mitigation (Batres et al., 2021). However, there are emerging circumstances in which developing countries have had to become part of global mitigation goals. First, to be an active player in international climate change negotiations, many countries like Pakistan have made mitigation commitments under the Paris Agreement (Pak-NDC, 2016). However, developing countries like Pakistan did not factor in the impact of transnational development projects like the BRI, B3W, and the EU's global development framework while announcing carbon reduction commitments through NDCs. These transnational development and infrastructure projects could compromise the emissions reduction goals of those host countries that are part of transnational development projects (Hilton, 2019). In this situation, developing countries would not be justified in blaming developed countries alone for global emission increases. Developing countries may have to consider options like CDR to curtail domestic carbon emissions and stay committed to emission reduction goals under the Paris Agreement while hosting transnational infrastructure and development projects.

Developing countries view climate change as primarily caused by the global North and believe they have more pressing concerns like poverty alleviation, energy security, and attaining development. Developing countries are minimally engaged in mitigation discussions and even less engaged in climate engineering and CDR discussions (Sovacool, 2023). However, the IPCC's recent reports under AR-6 tell us that developing countries must be much more involved in the Paris Agreement goals to be met, including CDR. One potential way to attract developing countries towards CDR as a climate

policy option is to reframe CDR as a development. CDR is a method by which developing states could reach their development goals and, per Sen, could increase their capabilities. We must look to major development initiatives like the BRI to consider and examine CDR as a development. First, BRI-type projects have enormous transnational environmental implications, and second, these projects may have governance structures for the application of just CDR. BRI provides an avenue to see how CDR might be incorporated into development patterns and institutions in developing countries. The critical question is, why look at BRI? Because BRI is a most significant development initiative and has a south-south dimension. This reframing CDR as development may push CDR in a particular direction. CDR as development may be implemented very differently than CDR as pure mitigation. This chapter aims to explore CDR as development in the context of the BRI.

To understand CDR for development, there is a need to understand the link between human well-being and carbon emissions. Carbon emissions, energy needs, and human well-being are interconnected factors that impact human development (Li & Chen, 2021). Developing countries often prioritize development in global environmental negotiations due to financial constraints. For instance, in CBD, developing countries advocated revenue-sharing language for genetic resources, while the European Union favored a language that condemned crop engineering (Victor, 2008). The correlation between GDP growth and carbon emissions is evident in emerging economies such as China, India, and other developing countries. Despite the environmental consequences, many developing countries are willing to prioritize economic growth. The correlation between economy, politics and global environmental governance and CGE has been explained by Simon Dalby:

Given the interconnectedness of climate matters as well as the globalization of the economy, these things require multilateral institutions and economic innovations simultaneously. But precisely because the global political economy has failed to generate such things, the assumption that emergency efforts at geoengineering will be tried in their absence underscores both the urgency of addressing these experiments and the need to try to put some international governance structure into place (Dalby, 2015, p.196)

Dalby suggests the need to restructure major political economy institutions like the BRI. It is not just a matter of reframing the BRI as a green institution. Still, the BRI's institutional machinery must be assessed to see if it can incorporate just CDR. This situation indicates that all countries, but especially developing need to take CDR (overall CGE) seriously because it seems that some kind of CGE is inevitable as countries' priority is economic growth in the presence of emission reduction

responsibilities under the Paris Agreement. Developing countries must manage their economic growth to avoid poverty and attain sustainable development while meeting emission reduction goals they have committed to under the Paris Agreement (Paris Agreement, 2015, Article 6(8)). Article 2 of the Paris Agreement states that all nations will restrict the global average temperature to well below 2 °C and make efforts to limit the global average temperature by 1.5 °C. The Paris Agreement also provides some instruments to ensure the attainment of these goals, like ensuring the smooth flow of climate finance (Article 2 (C)) and the reduction and removal by sinks of GHG (Article 4).

The primary objectives of this case study are to explore the concept of CDR within the context of the Pakistan-China relationship and to evaluate the BRI as a pathway for achieving equitable CDR. In my analysis, I aim to address two key questions: First, can CDR enhance Pakistan's capabilities, particularly within the framework of initiatives like the BRI? Second, can the BRI effectively facilitate the implementation of CDR technologies in Pakistan?

In my analysis, I aim to address two key questions: First, can CDR enhance Pakistan's capabilities, particularly in the context of initiatives like the BRI? Second, can BRI facilitate implementation of implementation of CDR technologies under the BRI? The case study findings reveal that CDR holds substantial potential and offers opportunities aligned with Pakistan's development objectives. These benefits encompass improved energy access, economic growth through carbon credit creation, advancements in agriculture, adaptation strategies, and indirect climate advantages. A key insight is that these climate-related benefits depend on Pakistan retaining carbon credits rather than transferring them to China. The second question explores whether the BRI can facilitate these benefits in its initial phase. The study suggests that the initial phase of the BRI, being heavily infrastructure-focused and primarily serving China's economic interests, offers limited scope for delivering direct or indirect benefits to host countries. However, in its second phase, the BRI shows a strategic shift towards a "small is beautiful" approach, emphasizing greener and more sustainable outcomes for participating nations.

Role of the Capability Framework for CDR under the BRI in the Case of Pakistan

The capability framework, derived from Amartya Sen's capability approach, provides a powerful framework for evaluating development projects in diverse and multidisciplinary fields. By focusing on human well-being, freedoms, and equity, this framework can help ensure that CDR projects under the

BRI address environmental challenges and contribute to broader human development goals in Pakistan.

The primary goal of CDR under the BRI is to enhance the well-being of Pakistan's population by reducing CO₂ concentrations and mitigating climate change impacts, particularly in vulnerable regions. Often facing challenges such as droughts, heatwaves, and water scarcity, these areas stand to gain long-term security and resilience through effective CDR implementation (Siddiqui, 2022). However, for meaningful development, CDR initiatives under the BRI must extend beyond environmental objectives to actively support Pakistan's socio-economic progress. Projects BECCS, afforestation, and soil carbon sequestration (SCS) should not only address carbon removal but also create employment opportunities, boost agricultural productivity, and improve rural infrastructure, aligning with the country's broader development goals (Congress.gov, 2024). CDR efforts should include measures that provide protective security to the most vulnerable communities. This could involve ensuring climate adaptation strategies, such as flood protection or drought-resistant agricultural techniques, are integrated into CDR projects, reducing climate-related vulnerabilities (Congress.gov, 2024). The goal is to ensure these projects protect communities from environmental risks while enhancing their long-term resilience to climate change.

For CDR projects under the BRI to succeed, they must be designed and implemented with the democratic participation of local communities. This involves engaging stakeholders from local governments, civil society, and affected communities to ensure CDR strategies align with local needs and priorities. Pakistan's decentralized governance system offers opportunities for this type of participatory process. BRI-related projects need to be transparent and inclusive in their decision-making structures, empowering local communities to shape their future.

A core requirement of the capability approach is informed consent, ensuring that communities affected by CDR projects are fully aware of the potential benefits and risks. Under the BRI, CDR projects must be implemented to empower local populations to have a say in deploying these technologies, whether they involve land-use changes for afforestation or industrial-scale carbon capture. This respect for local knowledge and perspectives is integral to the success of CDR projects. Communities should be free to choose whether or how they engage with CDR projects under the BRI. They must be provided with the agency to influence project design and implementation rather than being passive recipients of foreign investment or top-down interventions. This will ensure that CDR

projects respect local values, culture, and livelihoods, particularly in rural and indigenous communities that depend on land and natural resources for their subsistence.

Effective self-governance is essential for the success of CDR projects under the BRI. Local governments and institutions must have the capacity and autonomy to manage and oversee CDR initiatives. Strengthening Pakistan's environmental governance institutions will allow them to coordinate large-scale CDR efforts while ensuring they align with local development priorities. The institutions responsible for implementing CDR projects under the BRI must act with a fiduciary duty toward the people of Pakistan, ensuring that the projects are designed and managed in ways that prioritize the long-term well-being of the population. This involves ensuring that the benefits of CDR projects, such as job creation and environmental protection, flow equitably to all segments of society, especially marginalized and vulnerable populations.

The impartial spectator principle demands that the design and governance of CDR projects consider best practices from a global perspective at the implementation stage of CDR initiatives. In Pakistan, this means that CDR projects under the BRI should not only be implemented focusing on local interests but also in a way that aligns with the parameters of UNFCCC or UNEP. These projects should ensure that Pakistan's climate efforts align with international commitments, such as the Paris Agreement, and contribute positively to the global effort to combat climate change.

The outcome of CDR projects under the BRI should be the promotion of enhanced justice, ensuring that the benefits of these projects are distributed equitably and that no community bears a disproportionate burden. This is particularly important in Pakistan, where regional disparities in development and climate vulnerability are significant. BRI-related CDR projects should prioritize regions most affected by climate change and poverty, ensuring that these areas receive the investment and support needed to build resilience and improve livelihoods.

A solid informational base is necessary for the successful implementation of CDR projects. This involves conducting thorough environmental and social impact assessments to ensure that CDR strategies are feasible, effective, and sustainable. Under the BRI, Pakistan can benefit from international knowledge-sharing and collaboration with Chinese partners to build the technical and institutional capacity needed for CDR implementation.

The Eyes of Mankind principle at the outcome stage refers to the global recognition that CDR projects in Pakistan under the BRI contribute to national development and the global effort to combat climate

change and their impact is assessed by a neutral body. These projects should align with international climate goals and be recognized as part of the global movement toward sustainability and climate justice. By reducing carbon emissions and promoting sustainable development, CDR efforts in Pakistan can serve as a model for other developing countries facing similar challenges.

The capability framework provides a comprehensive guide for evaluating and implementing CDR projects under the BRI in Pakistan. By focusing on human well-being, inclusive governance, and just outcomes, this framework ensures that CDR initiatives effectively mitigate climate change and align with Pakistan's broader development goals. Through democratic processes, informed consent, and transparent governance, CDR projects can contribute to environmental sustainability and human development, enhancing the capabilities and freedoms of communities across Pakistan and addressing the global challenge of climate change.

Carbon Dioxide Removal (CDR)

CDR is a combination of various techniques, and all the techniques involved in CDR are different in terms of their costs, benefits, time of deployment, and potential to remove CO₂ (IPCC, 2018, 2023). Intergovernmental Panel on Climate Change (IPCC) has defined CDR as:

Carbon dioxide removal (CDR) anthropogenic activities removing CO₂ from the atmosphere and durably storing it in geological, terrestrial, or ocean reservoirs, or in products. It includes existing and potential anthropogenic enhancement of biological or geochemical sinks and direct air capture and storage but excludes natural CO₂ uptake not directly caused by human activities (IPCC, 2018, p. 544).

The CDR techniques can be categorized into nature-based techniques and artificial techniques. Although the scenario pathways rely heavily on CDR techniques to limit global warming to 1.5°C, most techniques are not ready for deployment, nor are they widely accepted for implementation by the public (Honegger et al., 2018). The feasibility of CDR has been studied in various models to control the increase in emissions. Still, the uncertainty and potential implications of CDR pose a significant challenge in the deployment of CDR. According to IPCC (2018), different mitigation schemes can lead to pathways that restrict temperature to 1.5 °C with no or limited overshoot, but in most scenarios, CDR is required. CDR was introduced into scenario analysis after IPCC's AR5 report, in which 104 out of 116 scenarios depend on BECCS to achieve a 2 °C target (Fuss et al., 2016, p. 2). All pathways that

suggest limited or no overshoot over 1.5 °C use CDR for carbon removal on the order of 100–1000 gigatons of carbon dioxide (GtCO₂) in the twenty-first century (Fuss et al.,2016). IPCC has noted that:

In addition to deep, rapid, and sustained emission reductions, CDR can fulfill three roles: lowering net CO₂ or net GHG emissions in the near term; counterbalancing ‘hard-to-abate’ residual emissions (e.g., some emissions from agriculture, aviation, shipping, industrial processes) to help reach net zero CO₂ or GHG emissions, and achieving net negative CO₂ or GHG emissions if deployed at levels exceeding annual residual emissions (IPCC, 2023, p. 52).

This multidimensional role of CDR in future environmental policies makes it imperative for developing countries to engage themselves in technology and governance debates related to CDR. In addition, CDR’s demand and supply depend not solely on technological issues but also on social acceptance, economic viability, and sustainability levels; therefore, an interdisciplinary approach is required to investigate the options (Fuss et al., 2016). A significant amount of attention has been paid to assessing the capacity of CDR and its impacts, but generally on a global scale. The gap exists regarding CDR capacity in developing countries as there is very little work here. Moreover, it is also important to investigate the key CDR types potentially relevant in Pakistan: afforestation, reforestation, BECCS, biochar, and DACCS. Pakistan has the feasible geology for nature-based techniques like afforestation, reforestation, and blue carbon.

CDR's feasibility in developing countries largely depends on the nature and extent of developing countries' partnerships with big economies like China and the USA. China’s BRI offers multidimensional support and assistance to BRI host countries, and CDR’s role as a climate policy option deserves attention.

CDR as Development

As enunciated by the capability framework, the link between CDR and development must place human capabilities at the center while dealing with environmental issues. The capability approach treats a sustainable environment as meta-capability, like food and health, and encourages humans to protect their environment (Holland, 2012) proactively. The constructive agency of people to preserve and protect the environment is one of the many development achievements (Sen, 2009, p.249). The capability framework advocates that humans are the most powerful creatures on earth because of their knowledge and resources. Therefore, human beings should assume a leading role in preserving

the environment for themselves, future generations, and species that cannot exercise similar options as humans (Sen, 2009). Therefore, if CDR can help to remove the carbon and protect human capabilities threatened due to climate change, it will collectively benefit current and future generations' development and environment through human agency.

Sen's capability theory offers profound insights into development, with a particular emphasis on capabilities, freedoms, and justice. At its core, capability refers to an individual's ability to lead a life they value and have reason to value (Sen, 1999, p. 17). These capabilities are not static; they can be enhanced through well-designed public policies and active civic participation, both of which contribute to shaping more effective and inclusive policies (Sen, 1999). Central to Sen's framework is the concept of freedom, which he identifies as both the primary objective and the essential means of development. Freedom, in Sen's view, encompasses multiple dimensions—political, economic, social, and cultural—and aims to eliminate human deprivations while expanding opportunities for individuals to thrive (Sen, 1999). However, freedom and agency are not exercised in a vacuum; they are profoundly shaped by social, political, economic, and geographical structures, which can either empower or restrict an individual's ability to realize their full potential. Development, therefore, involves the removal of various forms of unfreedoms that limit people's choices and hinder their capacity to exercise reasoned agency (Sen, 1999, p. xi).

The concept of justice in the capability approach also suggests how freedom and capabilities can be attained. The absence of perfect justice should not be the key consideration, but the non-redressal of remedial justice is more important (Sen, 2009, p.vii). Sen attributes remedial justice as the key impetus for the existence of some of the most significant political struggles that humanity has witnessed, ranging from Gandhi's non-violent movement to Martin Luther King's dreams. These political leaders were not trying to attain perfect justice but to reduce injustice as much as possible (Sen, 2009, p. Vii). Moreover, Sen disagrees with the prominent view of many justice theories, which solely focus on establishing "just institutions," instead, Sen emphasizes the actual implications of a justice initiative for human lives (Sen, 2009). Sen argues for a justice approach that can improve the lives of human beings.

CDR has significant development potential and should be viewed as an innovative form of development. In Sen's terms, climate change represents a profound source of unfreedom, restricting choices, livelihoods, and opportunities for millions. Any climate policy option, including CDR, that mitigates the adverse impacts of climate change must therefore be recognized as a pathway to

restoring freedoms. CDR is not only an environmental intervention but also a contributor to societal well-being. Through mechanisms like offset markets, it can generate funding and foster sustainable growth in critical sectors such as energy and agriculture, ultimately contributing to expanding the capabilities of communities most affected by climate change. In essence, the integration of CDR into development frameworks aligns closely with Sen's vision of development as freedom. By addressing the constraints imposed by climate change, CDR serves as both a tool for environmental restoration and a means to enhance human capabilities, ensuring a future where individuals and communities can thrive without the burden of climate-induced unfreedoms.

As part of a comprehensive climate response, CDR plays a significant role in addressing mitigation shortfalls and can serve as a complement—not merely a substitute—to emission reduction efforts. From a development perspective, CDR helps safeguard environments threatened by excessive carbon emissions while enabling ongoing development processes. This dual role aligns with the capability framework's notion that a sustainable and healthy environment serves as a meta-capability, essential for supporting other dimensions of human development. Furthermore, CDR offers a practical pathway for developing countries to balance industrialization and emissions control, particularly in sectors crucial for economic growth and under transnational initiatives such as the BRI. Interviewee (A) aptly described this dilemma as "the paradox that there has to be development and there has to be a reduction in CO₂ emissions." The IPCC in its Sixth Assessment Report (AR6) has underscored the essential role of CDR in achieving net-negative emissions, especially in addressing hard-to-abate emissions in sectors such as aviation and agriculture (IPCC-AR6, 2023, p. 22).

One of CDR's most significant contributions to development lies in its diverse co-benefits. Technologies such as BECCS offer pathways for energy generation, while blue carbon initiatives support coastal adaptation and protection. Biochar improves soil fertility and enhances agricultural productivity, and afforestation and reforestation bolster soil stability and flood resilience. For developing countries, CDR presents an opportunity to align climate action with the attainment of SDGs, ensuring long-term environmental and social well-being (Algayerova et al., 2021). In countries like Pakistan, where energy crises are persistent, feedstock cultivation for BECCS holds significant potential for clean energy generation. Similarly, Pakistan's mangrove forests provide a foundation for advancing the blue economy, combining environmental conservation with economic opportunities. The IPCC has consistently highlighted CDR as an essential strategy for achieving global net-negative

emissions and addressing hard-to-abate sectors, underscoring its critical role in sustainable development pathways:

Similarly, depending on the context, biological CDR methods like reforestation, improved forest management, soil carbon sequestration, peatland restoration and coastal blue carbon management can enhance biodiversity and ecosystem functions, employment and local livelihoods (IPCC-AR6, 2023, p.22).

Moreover, CDR projects have the potential to contribute significantly to technological and human capacity building in host countries, particularly under transnational development initiatives like the BRI. Advancing CDR research requires substantial improvements in technological and scientific infrastructure, which, in turn, can foster innovation and local expertise. Sen's capability framework emphasizes technology and knowledge as crucial resources for fully realizing production possibilities and development opportunities (Sen, 1999, pp. 162-163). Through partnerships under the BRI, collaboration between China and developing countries could evolve into robust technological and knowledge-sharing arrangements. As Interviewee (A) noted, "technologies provide enormous opportunity to not only scale up the development process but also to tackle the climate." However, technology acceptance can vary across regions. Interviewee (A) highlighted that technologies addressing immediate needs—such as increasing rainfall in arid regions—are more likely to gain acceptance. Similarly, climate technologies like CDR will be embraced if they demonstrate tangible benefits to people's lives and livelihoods. This acceptance is particularly evident in regions grappling with desertification, drought, water scarcity, and extreme weather conditions, where such interventions directly address existential challenges. Ultimately, the broader acceptance of CDR in the Global South hinges on its capacity to safeguard critical capabilities threatened by climate change, including food security, health, and energy access.

CDR is a vital mechanism in the global fight against climate change, involving the extraction of CO₂ from the atmosphere and its long-term sequestration (IPCC-AR6, 2023). Its primary goal is to reduce greenhouse gas concentrations and alleviate the impacts of climate change (IPCC, 2018). However, when analyzed through the lens of development and Sen's capability approach, CDR emerges as more than a technical solution—it becomes a developmental tool with the potential to enhance freedoms, improve well-being, and ensure long-term sustainability. From a socio-economic perspective, CDR strategies offer opportunities to address energy challenges, boost agricultural productivity, and drive

sustainable development (IPCC-AR6, 2023). Aligned with human development goals, CDR contributes to a development process that expands freedoms and improves human capabilities.

By actively removing CO₂, CDR technologies stabilize the climate and reduce the frequency of extreme weather events such as floods, droughts, and heatwaves. This enhances community resilience, safeguarding lives and livelihoods (Congress.gov, 2024). Additionally, CDR initiatives can stimulate local economies by creating employment opportunities in technology deployment, reforestation, bioenergy production, and carbon capture infrastructure. These projects hold immense potential for inclusive economic growth, particularly in developing countries where investments in green technologies can drive socio-economic transformation.

For CDR initiatives to succeed, robust institutions and governance structures are essential. These must prioritize transparency, equity, and inclusivity, ensuring that development efforts are economically viable and socially just. As demonstrated by large-scale projects like the BRI, governance frameworks play a pivotal role in managing environmental and social trade-offs (Batres et al., 2021). In the context of CDR, this entails involving local communities in planning and decision-making, safeguarding against unintended social or environmental harms, and ensuring equitable benefits. Inclusive governance, informed consent, and equitable participation are fundamental principles for successful CDR projects.

For example, BECCS can simultaneously address carbon removal and agricultural development, contributing to energy security while reducing carbon emissions. By integrating climate action with development goals, CDR initiatives can act as transformative tools that not only mitigate climate risks but also empower societies to achieve sustainable and inclusive growth.

Belt and Road Initiative (BRI)

The BRI is a multidimensional and multinational development project connecting roads and providing sea and energy links at regional and international levels. BRI is a grand project of China to enhance regional influence, strengthen economic linkages, and gain an advantage in global geopolitics (Flint & Zhu, 2019). BRI is the brainchild of President Xi Jinping, as President Xi announced this project on two different occasions. First, he announced the Silk Road Economic Belt (SREB) in Kazakhstan in September 2013. In December 2013, he announced the Maritime Silk Road (MSR) in Jakarta, and these two announcements laid the initial foundation of the BRI (Ivleva, 2021). According to the United Nations Economic and Social Commission for Asia and the Pacific (ESCAP):

(BRI) is the name given to the series of outline plans now being promoted by China for greater economic cooperation and integration across a vast region extending to China's west and South. In full, the Belt is the Silk Road Economic Belt (seen as the overland linking of western China to Central Asia and Europe); the Road is the 21st Century Maritime Silk Road (the sea lanes from China to Southeast Asia and the Middle East) (ESCAP, 2017, p., 583).

BRI's primary purpose is to find new markets for Chinese state-owned enterprises (SOEs) surplus capital and construction material (Merwe, 2019), and it has a significant economic attraction for the host countries. BRI is a win-win situation because host developing countries have a growing demand for infrastructure and energy resources like power plants and in contrast, China has surplus capital to meet these demands (Carey & Ladislav, 2021). China has designed BRI as a dynamic project to cater to the emerging needs of the host countries. For example, to cater to the specific needs of rich countries of the Middle East in areas of renewable energy and digital transformation, China has introduced the concept of "small and beautiful" (Yeung, 2024).

However, BRI has been criticized for multiple reasons. Like, China is creating a debt trap for the host nations, upsetting the global political order and, on the environmental side, threatening the global efforts to mitigate carbon emissions (Rana & Ji, 2019; Lew et al., 2021). The climate-change-related implications of the BRI are crucial because there are apprehensions that a carbon-intensive development under the BRI may compromise the emission reduction trajectory of the host countries and goals to limit the global average temperature under the Paris Agreement. The successful implementation of the Paris Agreement depends on the emissions trajectories of the BRI partner countries and the infrastructure choices they make today (Ivleva, 2021, p. 6). BRI is a vast infrastructure project, and related carbon emissions, mainly due to coal-powered plants and subsequent environmental impacts, have become part of the policy and academic debates (Chao, 2018). For the first time, the host countries (mainly developing countries) will have to defend their domestic carbon emissions due to BRI-sponsored projects during international environmental negotiations instead of blaming the global North for the global emission increase. This situation contrasts with Article 4 of the Paris Agreement (2015), which suggests that developing countries make all possible emissions reduction efforts and increase mitigation measures. According to Nicholas Stern:

The more than 70 countries that are signed up to the Belt and Road Initiative," he said, "have an average GDP of around one-third of that of China. If they adopt China's development

model, which resulted in a doubling of China's GHG [greenhouse gas] emissions in the first decade of the century, it will make the emissions targets in the Paris Agreement impossible (see Hilton, 2019).

Two critical factors contribute to increased carbon emissions in the host countries under BRI. The first is economic development and the second is carbon emissions because of energy consumption (Lew et al., 2021; Fan et al., 2019). There is also a concern among the international community, especially in the USA, that environmental practices under the BRI do not match the best practices in the world (Lew et al., 2021). Belt and Road Countries (B&RCs) and China together make around half of the world's GHG emissions. Therefore, China's choice of fuel for energy investment and environmental impact assessment (EIA) in the host countries will play a key role in determining the world's overall response towards climate change (Carey & Ladislaw, 2021). Overall, China's role in high carbon development can be analyzed in two ways: first, China's domestic carbon emissions, and second, China's role in external emissions in the host countries as a partner and sponsor of the BRI. The answer to the first part is that China has done a good job by reducing domestic emissions, promoting renewable energy, and reducing the reliance on coal (Mathew & Tan, 2017). China has announced it to peak its emissions by 2030 and attain carbon neutrality by 2060 (Chunying, 2021). These aims from China suggest that China may consider high carbon removal options. In its 13th five-year plan for energy development, China has committed to reducing reliance on coal energy production and increasing renewable energy use (ESACP, 2017). China has made significant pledges to improve its domestic environmental standards and manage climate change risks in recent years. However, improvements in China's domestic environmental standards need to be evaluated critically as the BRI has allowed China to export its domestic emissions to host countries of the BRI. According to an estimate, 'total carbon emissions of B&R countries were 5473.14 Mt in 2004 and 6616.71 Mt in 2017 excluding China, an increase of 20.9%' (Zhang & Chen, 2022). So, there are concerns about China's claim of improving its environmental standards as China might have compromised the environmental situation in its partnering countries.

However, there is a bigger concern about China's role in increasing emissions in the host countries of the BRI. For example, China can increase its domestic environmental safety by relocating its old and inefficient energy production facilities to partner countries, but it may deteriorate the environmental situation in the host countries (Yang & Yang, 2019). There is a widespread concern that China exports black energy because of coal power plants to B&RCs (Mathew & Tan, 2017). Many developing

countries face an acute energy crisis that compromises economic development and human well-being. Some developing countries have started importing coal-fired power plants from China under the BRI to resolve this energy crisis. "Coal is also perceived to be cheaper, more reliable (particularly for large baseload power), and easier for older grid systems to absorb" (Lew et al., 2021, p.56). A primary reason for such popularity of coal power plants in developing countries is the easy financing of coal-fired power plants from China (Lew et al., 2021). China's partnership regarding coal-fired power plants contradicts the policies of many developed countries like the USA, which have eliminated financing for overseas coal-fired power plants (Lew et al., 2021). This reliance of B&RCs on carbon-intensive energy projects is due to their domestic energy crisis and inability to arrange finance for expensive renewable energy technology. The coal power plants contribute to emission increases but carry severe risks to human health and natural habitats. For example, coal power plants are causing the rapid melting of glaciers, especially in South Asia, and threatening a critical water source (Mani, 2021). The partnering countries of China are in a tight situation because installing coal-fired power plants to avert the energy crisis can significantly increase domestic emissions. In this way, the host countries are risking their sustainable development goals.

China's major partnership with developing countries is in the energy sector, mainly through coal power plants is also visible in the financial cooperation under the BRI. China's two largest policy banks—the China Development Bank (CDB) and the China Export-Import Bank (EXIM)—now provide as much energy finance to foreign governments as all multilateral development banks (MDBs) combined. With more than a fifth of this money going toward coal since 2001 and fully three-quarters to some fossil-fuel investment, the climate change implications of the BRI are highly problematic (Carey & Ladislav, 2021, p.1). China's financial support for coal-powered plants and fossil fuel-related projects has created a sense of apprehension among the international community that China might indirectly compromise the emission reduction goals envisioned under the Paris Agreement.

The transportation and communication sector is another source of notable emissions under the BRI in the host countries. Climate change-related risks are spread over a geographical area through rail and road networks and have environmental implications on forest cover increase in carbon emissions (World Bank (b), 2019). A report from the World Bank has suggested that transport infrastructure under the BRI is projected to increase carbon dioxide emissions by 0.3 percent worldwide—and in some countries, it could be 7 percent because of higher emissions (World Bank, 2019). The road and rail

network increases emissions and harms indigenous people's forest cover, natural habitat, and livelihoods. The direct emissions from the BRI projects may need verification, but the reduction in forest cover can easily be gauged through satellites and other technologies; this impact of BRI is undeniable due to transport and infrastructure development (Worldbank (b), 2019, p.51). Then, all the resource extraction activities and supply chains will increase emissions in China and the host countries. China's cement sector comprises 15% of China's emissions, and for BRI alone, China plans to open 100 new cement factories, which will ultimately require more mining and transportation (Hughes, 2019). These multidimensional environmental risks associated with the BRI have raised a serious question about the ability of host countries to curtail their carbon emissions while implementing the BRI.

On the other hand, some scholars argue that the BRI may contribute to reducing emissions in specific sectors over time. For instance, Schinas and von Westarp (2017) suggest that new maritime routes established under BRI could decrease the number of vessels at sea, reduce transportation costs, cut emissions, and shorten travel distances and time. However, the potential benefits of emission reductions in isolated sectors should not overshadow the broader environmental concerns. Areas where the BRI could significantly increase greenhouse gas emissions must remain central to policy discussions and mitigation strategies to ensure a balanced and sustainable approach.

In response to severe criticism of the climate change implications of the BRI, the Chinese government has announced several initiatives to minimize the adverse impact on the environment of the BRI. Chinese political leadership appears to be ready to incentivize B&RCs to reduce the carbon footprint of the BRI. That is why the Chinese leadership has coined terms like ecological civilization, the greening of the BRI, and South-South environmental cooperation (Asienhaus, 2017). To address increasing criticism, the Chinese leadership has described development, green infrastructure projects, and green financing as interrelated initiatives (Chunying, 2021). According to the Chinese Foreign Ministry spokesperson,

Climate change is a global challenge that requires all parties to work together to demonstrate leadership. China is ready to work with all parties to promote the full and effective implementation of the Paris Agreement and work together to build a win-win, fair and reasonable climate governance system to contribute to the global low-carbon transformation and post-epidemic green recovery (Chunying, 2021).

All the initiatives taken or announced so far by China for the greening of the BRI have created a limited impact on addressing the issue of emission increase due to BRI projects in the host countries. China has initiated several steps to rebrand the BRI as a green BRI; most of these initiatives have little impact because many environmental assessments in the host countries are voluntary (Lew et al., 2021). That is why there is a growing demand that Chinese financial institutions stop using the "host country standard" to evade the rigorous environmental standards required according to the goals of the Paris Agreement (Voituriez et al., 2019).

Developing countries have remained critical that developed countries use their financial clout to seek favorable terms in various agreements regarding climate change. In this situation, China has emerged as a significant alternative donor for them (B&RCs) without imposing strict conditionalities (Xing, 2018(b)). BRI also has many characteristics of the Marshall Plan for developing countries (Shen, 2016). By establishing the Asian Infrastructure Investment Bank (AIIB), the first multilateral development bank outside the Bretton Woods system, China has created the leverage to provide finance to developing countries through a multilateral arrangement outside Western influence. Due to the emergence of AIIB, the intent of Asian economies, particularly China, is clear: to play a more active role within global governance but with specific Asian values (Ong, 2017). Most developing countries consider the BRI an alternative for their financial and development needs to the Bretton Wood system, as the BRI projects significantly influence host countries' economic growth (Xing, 2018; Chen et al., 2019). China has created a US\$40 billion Silk Road infrastructure fund, which invests in BRI infrastructure projects. Establishing another development bank under BRICS, with an initial capital of US\$50 billion, has established solid financial support for any initiative led by China (Sooklal et al., 2018). China's overseas development assistance is approximately one-third of the global development assistance program (Carey & Ladislav, 2021, p.1). The financial allocation made by China for its overseas engagement, including for coal-fired power plants, makes it an easy and attractive cooperation partner for many developing countries, especially those that face energy scarcity. China has been actively engaged in overseas investment for years, but Chinese engagement has gotten more formal recognition under the BRI. The proponents of the BRI describe it as a development resource for many developing countries.

The primary structure of the BRI is south-south cooperation, in which China has a dominant role. The key difference between the traditional official development assistance (ODA) model and Chinese cooperation under the BRI is that BRI has fewer conditionalities regarding human rights, governance,

and political activities. BRI's composition can shift global arrangements and bring new aspects to international relations (Xing, 2018(b)). An essential aspect of emerging environmental governance is south-south cooperation between China and the host countries of the BRI from the global South (China-NDC, 2022). As interviewee (C) described, "China has been promoting south-south cooperation and has been promoting itself as a provider of development, finance, and development grants and so on (and) established a counterweight to western-dominated multilateral development institutions." This south-south cooperation between China and other developing countries is attractive for host countries of BRI, given the apprehensions of developing countries about existing structures of global environmental governance and the dominance of Western countries in the policymaking of the concerned institutions.

A China-led partnership for CDR needs serious consideration, as the global South is an increasingly important area regarding emission increase and CDR research. Due to transnational economic and infrastructural developments and subsequent environmental implications, some countries like China and Russia can impact the pattern of global emissions outside their geographical territories. One crucial shift in global structures is the rise of emerging economies of Brazil, Russia, India, China, and South Africa (BRICS) countries (Clapp & Helleiner, 2012). These emerging economies have a unique role in global environmental governance because of their economic and political influence and environmental scarcity (Homer-Dixon, 2001). Among all five emerging economies in BRICS, China is the most prominent and influential country regarding financial and geopolitical clout. The competition between the Western powers and China is quite visible in their respective engagement in developing countries, primarily because of their mutual desire to capture the energy and natural resources in the developing regions (Gu et al., 2008). As the chief sponsor of the BRI, China can link the economic interests of BRICS and the remaining countries in the global South.

The research has shown that BRI projects have significantly influenced the economic growth of host countries (Chen et al., 2019). It reflects the host country's agency in the governance of the BRI. Usually, there is a general perception that China has unilaterally structured and shaped CPEC in Pakistan, but Pakistan has exercised its agency wherever necessary (Adeney & Boni, 2021). For example, due to the shortage of electricity and the abundance of coal resources in the country, Pakistani governments even proposed establishing a "coal corridor" to secure energy through domestic resources (Dawn, 2013; Adeney & Boni, 2021, p.2). Unlike many Western institutions and countries, unconditional and accessible financial assistance for the BRI countries has made BRI attractive to developing countries

(Lew et al., 2021, p.4). This governance model of the BRI in which China is not dictating the terms and conditions of operationalization of the BRI upon the host countries is also visible in the environmental governance of the BRI (Coenen et al., 2020). The potential economic opportunities for developing countries under the BRI and the unconventional governance model under the south-south cooperation make BRI a significant source of development and industrialization in the global South. However, this growth will significantly contribute to global emissions and challenges in implementing the Paris Agreement. This situation requires that options like CDR be seriously evaluated for their relevance and feasibility to the BRI, as mitigation efforts alone may not be enough. In the next section, I will discuss the potential of CDR initiatives under the BRI from China and a host country's perspective (Pakistan).

China's Motivation and Readiness for Promoting CDR under the BRI

To understand the potential of CDR under the BRI, we must analyze China's motivation (being the sponsoring country of BRI) for CDR and the host country's (Pakistan's) potential for CDR initiative. China and the host countries may look for a more aggressive approach like CDR to curb the emission increase under the BRI. CDR can be more impactful when applied at the regional or collaborative level. The countries' share of CDR varies greatly depending on which principle is applied. However, most importantly, the results highlight that unilateral action will not help achieve the total removal needed to reach 2050 and 2100 goals due to national biophysical limits (Pozo et al., 2020). Understanding China's motivation for CDR is crucial as it can have implications for almost all host countries of the BRI. China can support CDR for financial, social, and political reasons. An important consideration for China to pursue CDR under the BRI could be to assume a leadership role in environmental affairs in the global South. China's political and economic weight at the global level provides it with an edge in structuring the governance of CDR in the host countries. There is no uniform mechanism for the research and governance of technologies like CDR, so whichever country leads them also needs to have a particular political weight to research these technologies further (Interviewee-C). As interviewee (C) stated, China "will try to stay on top of low carbon industry technology, low carbon transportation technology, and all those newer technologies that have been developed like carbon dioxide removal (CDR) because all those things might have a demand." The interviewee (C) indicated

that there are chances that China itself will be interested in providing a low-carbon development solution to partnering host countries as time for action is limited, and infrastructure developments like BRI must become operational and sustainable in these challenging times.

In addition, pursuing CDR as a climate policy option aligns with China's vision to peak carbon emissions by 2030 and attain carbon neutrality by 2060. China has announced an action plan for carbon dioxide peaking before 2030, which suggests that China is keen to peak its carbon emissions and ultimately attain carbon neutrality. In its action plan, China has announced that it will take measures to improve the quality of carbon sinks. China has identified 4 steps to manage carbon sinks; the first is consolidating the carbon sequestration capacity of ecosystems in which China will be "making and implementing China's territorial space plans, we will work to form a new model of development and protection, which is conducive to peaking carbon dioxide emissions and achieving carbon neutrality" (NDRC, 2021). This plan's second component is enhancing ecosystems' carbon sink capacity, indicating that China is open to natural CDR. The plan suggests that:

We (China) will carry out large-scale programs to protect and restore major ecosystems. We will push ahead with large-scale afforestation and consolidate achievements already made in returning marginal farmland to forests and grasslands to increase forest and grassland resources (NDRC, 2021).

The third step is strengthening the foundation for ecological system carbon sinks through research, innovation, and technological developments. Chinese policymakers are open to technology for developing and maintaining carbon sinks. For this purpose, the action plan aims to "strengthen research on basic theories, basic methods, and cutting-edge, disruptive technologies in relation to carbon sinks in land and marine ecosystems" (NDRC, 2021). In this part of the action plan, China also aims to work for the establishment of carbon markets and trade mechanisms to make the carbon sink system sustainable and financially attractive. The fourth step is to use agriculture as a source of carbon sequestration, promoting carbon emissions reduction and carbon sequestration in agriculture and rural areas. The plan states, "We will research applied agricultural technologies that can increase carbon sequestration. We will improve the quality of cropland and protect China's chernozem soils, to enhance soil organic carbon content" (NDRC, 2021). This action plan for carbon peaking indicates that China is committed to a multidimensional approach to managing carbon emissions comprising natural and technological methods.

Moreover, China is motivated to label BRI as a green project, and CDR projects can deliver this image-building quickly. On the political side, China can appease its partner countries from the global South by working together on initiatives like CDR and presenting itself as an alternative to technology transfer to the Western countries. China announced several measures to attain carbon neutrality in the next few years, indicating China's willingness to explore CDR as a potential climate policy option for itself and partner countries of the BRI. As part of international cooperation and to make the BRI a green project, China plans to make the BRI a model of south-south cooperation in climate cooperation and promote technology and innovation (China-NDC, 2022). The announcements of greening the BRI are in response to criticism of the environmental impacts of the BRI. However, there are concerns about how initiatives for the greening of the BRI will address the environmental impacts of already executed projects because renewable energy can only work for new projects. An interviewee (C) pointed out that many projects under the BRI are not green at all from the beginning and have significant carbon emissions. The greening of BRI will have little impact on these existing projects. In this situation, CDR is a possible solution for greening the BRI that can address emissions from existing and upcoming projects. China aims to enhance cooperation with its partners in multiple ways. Technological collaboration under initiatives like the BRI includes advancements in renewable energy, energy storage systems, hydrogen power, carbon dioxide capture, utilization, and storage. Additionally, active participation in major international scientific projects, such as the International Thermonuclear Experimental Reactor Project, demonstrates the importance of cross-border partnerships in advancing global technological and environmental goals (China-NDC, 2022).

This international scientific cooperation under the BRI suggests China's readiness to explore innovative technologies for environmental and energy purposes. Pakistan's coal power plants have been installed through intensive technological and financial cooperation with China. In the future, China and host countries like Pakistan may also explore the feasibility of CDR to cut emissions under the BRI, especially those of coal power plants. In addition, CDR suits China's approach to collaboration while addressing environmental issues. China's action plan for 2030 identifies a few key areas for emission reduction through cooperation with the international community and member countries of the BRI (China-NDC, 2022). The areas of cooperation provide a broader framework for CDR cooperation amongst China and host countries of the BRI. Through this initiative, China intends to become an active and responsible member of the international community while following the principle of CBDR and urging the members of the international community to fulfill their obligations under the UNFCCC and the Paris Agreement toward emission reduction (China-NDC, 2022).

Understanding that China will consider the host countries' preferences for greening the BRI is crucial. If a host country has more inclination for CDR, China will likely be willing to cooperate on CDR research. Still, if the host country is willing to pursue development projects without emission control measures, China will also support this position. An interviewee (C) explained this situation and stated that:

The country (that) has rather strong regulations; China will follow it, but if it doesn't, China will not. So, in countries that do not have strong safeguards and a strong kind of rule of law or governance systems, it is definitely a big risk. Given that China is interested in making BRI a green project, countries with a better understanding of the CDR and the urge to use it as a development resource will likely be able to secure tailormade cooperation from China for CDR.

Capacity building of scientists, scholars, students, and policymakers from host countries of the BRI is crucial for initiating CDR research in developing countries. Several plans and policies under the BRI can support a bilateral or multilateral initiative on research and deployment of CDR by promoting knowledge sharing and technological cooperation amongst BRI and China host countries. These policies and plans include (i) a special plan on advancing cooperation of science and technology innovation in the Belt and road construction, (ii) a vision and action on jointly promoting agricultural cooperation on BRI, (iii) an education action plan, (iv) guidance on promoting green along BRI (v) the Belt and Road Ecological and environmental cooperation plan (vi) vision and actions on energy cooperation in jointly building silk road economic belt and 21st-century maritime silk road (vii) vision for maritime cooperation under BRI (viii) Guidance on Promoting Green Belt and Road (2017) (ix) Regulations of Belt and Road Scholarship Project for Foreign Students in Beijing (2017) (x) Special Plan on Advancing Cooperation of Science and Technology Innovation in the Belt and Road Construction (2017) (xi) The Belt and Road Vision and Actions for Cooperation in Metrology (2017), (xii) Vision and Actions on Energy Cooperation in Jointly Building Silk Road Economic Belt and 21st-Century Maritime Silk Road (2017) (source: Belt and Road Portal). There are indications that the Chinese academy might seriously consider partnering with the host countries regarding CGE research. In an interview, the academy president noted that "many countries have fragile ecosystems, and China also has similar issues," China has trained more than 1,800 scientists from BRI partner countries (Zhihao, 2017). CAS has set up nine overseas bases for cooperation in science and technology and launched more than 20 projects with the host country's partnership, including weather surveillance (Zhihao, 2017).

On the financial side, China may want to generate revenues by selling credits or ITMOs generated through partnerships with BRI host countries. China is exploring the options to develop carbon pricing mechanisms and carbon markets in partnership with the host countries of the BRI (BRIGC, 2024). Carbon credit generation is crucial as China launched its emission trading scheme in 2021. There are chances that Chinese ETS will gradually grow and include more stakeholders within it (Nakano & Kennedy, 2021). The launch of national carbon trading in 2021 incentivizes Chinese companies to incorporate carbon pricing into their business plans and help China attain carbon neutrality by 2060 (Koty, 2021). This deepening of the carbon trade market in China can be an important impetus for the private sector companies and corporations in China to explore CDR investment opportunities in the host countries of BRI, offset their carbon emissions, and trade these carbon credits in Chinese carbon markets. China can better attain its carbon peaking and carbon neutrality goals along with the sustainable development of the BRI host countries by working together in regional cooperation for emission reduction rather than having each country of the BRI work independently in silos (Hu, Da, & Wang, 2022). CDR's inclusion in BRI can be a significant game-changer for the Chinese carbon market, both domestically and internationally.

Harnessing CDR for Development in Pakistan under the BRI

Understanding Pakistan's unique economic, environmental, and infrastructural context is crucial for effectively integrating CDR strategies into its development framework, particularly under the BRI. This approach ensures that CDR initiatives deliver environmental benefits and align with Pakistan's broader development goals, addressing social, economic, and sustainability challenges. With a population exceeding 220 million, Pakistan is classified as a lower-middle-income country (World Bank, 2024). The country faces significant economic hurdles, including high poverty rates, limited industrialization, and a substantial informal sector. Agriculture remains a key pillar of the economy, employing a large workforce, while the industrial and service sectors are gradually expanding (Asian Development Bank, 2020).

The China-Pakistan Economic Corridor (CPEC), a flagship project of the BRI, has been instrumental in shaping Pakistan's development trajectory since its launch in 2015. By 2024, CPEC has facilitated the construction of power plants, highways, and the Gwadar Port, significantly contributing to economic growth and regional integration (Ministry of Planning, 2024). However, this development has also led to a rise in carbon emissions. Pakistan remains highly vulnerable to climate change impacts despite

contributing less than 1% to global greenhouse gas emissions. Severe climate-induced disasters, such as the catastrophic floods of 2022 affecting 33 million people, highlight the urgent need for robust climate resilience and adaptation strategies (UNICEF, 2023). Therefore, understanding Pakistan's socio-economic and environmental context is vital to position CDR as a pathway for sustainable development effectively:

Large energy supply and demand gap, high basket price of electricity due to the dependence on imported sources of energy, a sizeable population living below the poverty line, and prevailing water and food insecurity concerns accentuate the need to follow a high economic growth pathway. The Government of Pakistan (GoP) will, therefore, follow the greenhouse gases (GHG) emissions trajectory of 1603 Mt CO₂ Eq. for 2030 as announced in Pakistan's initial Nationally Determined Contribution (NDC) submission in 2016. However, realizing the importance of reducing the GHG emissions under Paris Agreement to limit the temperatures to 1.5/2°C, the GoP aims to reduce the emissions to the maximum possible extent. The GoP has taken a series of major initiatives as outlined in chapters 4 and 5. Hence, Pakistan intends to set a cumulative ambitious conditional target of overall 50% reduction of its projected emissions by 2030, with 15% from the country's own resources and 35% subject to provision of international grant finance that would require USD 101 billion just for energy transition. (NDC Targets & Means of Implementation, Pakistan Updated NDC-2021)

Integrating CDR strategies into Pakistan's development context offers an innovative pathway to address these challenges. With its significant energy supply-demand gap, reliance on imported energy, and vulnerability to climate-induced disasters, Pakistan stands to benefit immensely from CDR-led development. Pakistan can simultaneously reduce emissions, strengthen its energy security, and enhance agricultural resilience by investing in carbon capture and removal technologies, sustainable energy projects, and agricultural innovations. Additionally, international partnerships and financial support will play a crucial role in enabling Pakistan to leverage CDR for sustainable development, ensuring alignment with its broader economic and environmental objectives.

The CPEC, a flagship project of China's BRI, has significantly influenced Pakistan's infrastructure, energy, and economic development. As Pakistan seeks to balance rapid industrial growth with environmental sustainability, CDR emerges as a strategic tool to align climate action with national development goals. While early investments under CPEC heavily focused on coal and fossil fuel energy projects to address acute power shortages, recent efforts have shifted towards renewable energy

sources, including solar, wind, and hydropower. This evolving energy landscape offers a timely opportunity to integrate CCS technologies into both new and existing power plants, effectively reducing emissions. Moreover, energy projects under CPEC can incorporate strategies such as BECCS, afforestation, and soil carbon sequestration, enhancing their capacity for carbon removal and contributing to a sustainable development pathway (Melnikova et al., 2023).

About the industrial context, there are projects for Industrial zones and special economic zones (SEZs), which are essential elements of the CPEC and designed to enhance Pakistan's manufacturing capabilities and export potential. CDR opportunity is available through direct air capture (DAC) and other large-scale technology-driven CDRs that can be integrated into industrial zones (IEA, 2024). Incentivizing SEZ industries to adopt carbon-neutral or even carbon-negative practices can promote Pakistan's economic growth and environmental sustainability.

Highways, railways, and ports developed under the CPEC aim to position Pakistan as a regional trade hub. In conjunction with infrastructure projects, large-scale afforestation initiatives present a significant opportunity for long-term carbon sequestration while addressing challenges such as soil erosion, desertification, and biodiversity loss (Melnikov et al., 2023). The environmental impact can be further improved by integrating sustainable forestry practices along the Gwadar-Kashgar corridor. Infrastructure related to the CPEC must be resilient to the increasing frequency of climate-induced disasters, such as floods and heatwaves, that are affecting Pakistan. A promising avenue is the implementation of nature-based solutions, such as the restoration of mangroves and the conservation of wetlands. These initiatives not only serve as effective carbon sinks but also provide protection for vulnerable coastal and inland areas against climate impacts. This approach aligns well with CPEC's commitment to sustainable infrastructure development.

Agriculture continues to be a key area of focus under CPEC, with irrigation and water management initiatives aimed at enhancing food security. One significant opportunity lies in soil carbon sequestration through climate-smart agricultural practices, which can improve soil health, boost crop yields, and store carbon (Frank et al., 2024). This approach aligns with Pakistan's objectives of increasing agricultural productivity and tackling rural poverty.

Job creation is a fundamental promise of CPEC, as infrastructure and energy projects generate both direct and indirect employment opportunities. The CDR opportunity lies in training and equipping a workforce for CDR technologies, afforestation initiatives, and sustainable agriculture, all of which can

foster green jobs (McQueen et al., 2020). This approach would directly contribute to Pakistan's objectives of poverty alleviation and economic empowerment under CPEC.

Pakistan is part of several significant international climate commitments. In the context of CPEC development, as a signatory to the Paris Agreement, Pakistan aims to reduce its emissions by 50% by 2030, contingent upon international support. There is an opportunity to leverage the financial and technological partnerships facilitated by CPEC to implement large-scale CDR projects that align with these commitments and promote economic development. To achieve this, a Strategic Framework is necessary. Pakistan's climate policies, including the National Climate Change Policy, can incorporate CDR as a central strategy, establishing specific targets linked to CPEC projects. Additionally, attracting partnerships and financing is crucial. Developed countries like the USA are also evaluating CDR's potential role in attaining their national and international commitments regarding climate change (Congress.gov, 2024). CDR projects can draw green financing from international organizations and collaborate with China's green technology initiatives. It is also important to prioritize CDR-focused research and development within Pakistan's emerging technology centers associated with CPEC. Finally, promoting community involvement is essential. Engaging local communities in afforestation, soil carbon projects, and other CDR initiatives will ensure that development is inclusive and beneficial for all.

Pakistan's Potential for CDR under the BRI

Pakistan, located in South Asia and sharing a strategic border with China, stands as one of the largest beneficiaries of the BRI—a monumental Chinese infrastructure and investment framework. The historical geostrategic ties between Pakistan and China position Pakistan as a pivotal partner in climate-related cooperation under the BRI. In its NDCs, Pakistan has acknowledged the potential impact of the BRI on its emissions trajectory (Pak-NDC, 2016, p. 3). However, this acknowledgment calls for a deeper analysis of whether Pakistan can achieve its emission reduction targets solely through mitigation or whether it must also consider complementary strategies such as CDR. From the perspective of the capability approach, CDR can be seen not merely as a technical solution but as an enabler of development, enhancing Pakistan's ability to pursue sustainable well-being while addressing climate challenges. In countries like Pakistan, where per capita carbon emissions remain low, mitigation alone might not adequately address the developmental trade-offs associated with ambitious climate goals. CDR feasibility is inherently context-specific, shaped by economic, social, and

cultural factors. Yet, Pakistan's growing energy demands, reliance on local coal reserves, and opportunities for technological and financial collaboration with China—particularly in coal-fired power plants—highlight a strong case for integrating CDR into its climate and development strategies. By doing so, Pakistan can expand its capability set, balancing environmental responsibility with economic growth and improving societal well-being through sustainable climate governance.

The scarcity of energy in Pakistan has remained one of the most dominant factors in shaping the country's political, economic, and environmental landscape. Even in the case of CPEC, “energy came to be the very heart of the CPEC's initial phase largely because of a dramatic energy crisis that was affecting the lives and livelihoods of Pakistanis” (Adeney & Boni, 2021, p.6). Pakistan has significant coal resources, which makes coal power plants attractive for Pakistan (Rashid et al., 2020). Pakistan, since 2012, has added 20 341 MW of CO₂ emissions in Pakistan (GDPC, 2021). These carbon-intensive projects under the BRI make Pakistan an apt case for CDR research and collaboration. An interviewee (B) observed that although China has announced that it will not be building coal power plants under the BRI anymore, given the peculiar relationship between China and Pakistan, the CDR may become an important aspect of energy cooperation while pursuing fossil fuels fuel-based projects. Although China has announced to curtail its coal power cooperation with member countries of the BRI, the interviewees believed that given the energy shortage in countries like Pakistan, this promise might be challenging to fulfill. Pakistan has repeatedly faced an energy crisis in recent years, and given its abundant coal reserves, the political leadership of Pakistan is committed to exploring indigenous coal reserves and ending the energy crisis with the help of the Chinese government, even if it has environmental implications.

Any further increase in emissions resulting from the Belt and Road Initiative (BRI) could severely undermine Pakistan's emission reduction goals under the Paris Agreement and pose significant risks to the country's ecosystems. The fragmented and expansive nature of the China-Pakistan Economic Corridor (CPEC)—a flagship BRI initiative—makes it challenging to pinpoint the exact volume of emissions it generates. However, studies estimate that CPEC-related activities contribute approximately 51 million metric tons of CO₂ annually (Reynolds et al., 2018). Additionally, once the CPEC road networks, including the Karakoram Highway, are fully operational, they are projected to accommodate a significant increase in daily truck traffic, resulting in emissions of up to 36.5 million tons of CO₂ annually (Aslam, 2022). Given this trajectory, Pakistan emerges as a prime candidate for integrating green and low-carbon policies under the BRI framework to align infrastructure growth

with sustainable environmental goals (Jun et al., 2020). In this context, where CPEC-driven energy and infrastructure projects are poised to substantially elevate domestic carbon emissions, exploring CDR initiatives with Chinese cooperation becomes not only relevant but essential. Such collaboration could serve as a strategic pathway to balance economic development with environmental responsibility, ensuring long-term sustainable growth for Pakistan.

Pakistan's ambitious and innovative plans for carbon reduction and control are getting international attention and bringing a much-needed diplomatic respite for the government of Pakistan. Pakistan is an agricultural country, and natural CDR techniques like afforestation and reforestation have a natural appeal. Afforestation and reforestation for carbon synchronization help restore the natural ecological system and support the sustainable provision of water, food security, and employment opportunities (Perring et al., 2018). Pakistan's forest cover was just five percent at the time of submission of its NDC in 2016. Pakistan acknowledged this deficiency of the forest cover in its NDC and announced some initiatives to increase the country's forest cover (Pak NDC, 2016). Pakistan has initiated several afforestation projects and reforestation under the clean and Green Pakistan, like the Billion Tree Tsunami in Khyber-Pakhtunkhwa (KPK-a province of Pakistan) and the Ten Billion Tree Tsunami (TBTP). Pakistan's ambitious afforestation and reforestation have attracted international interest, and there is optimism that these extensive afforestation and reforestation steps will help in carbon sequestration in the country (UNEP(b), 2021). Due to these ambitious efforts, "the increase of forest area in KPK (a province of Pakistan) from 20.31% to 26.6% and greatly helped in increasing the forest cover by 6.3% during 2014-19" (UNEP(B), 2021). Under TBTP, around 3.296 billion plants will be planted by the end of Phase- I until 2023. These projects aim to improve forest cover and eco-tourism, protect wildlife, and engage the local community (UNEP(b), 2021). Besides these mass afforestation and reforestation campaigns, Pakistan aims to create 15 national Parks over 7,300 square kilometers. Some of these forest enhancement initiatives are so huge that few experts are considering these steps as a geoengineering approach to address the climate change issues of Pakistan. An interviewee (B) described this mass forestation campaigns in Pakistan in the following words:

When Pakistan says that we are thinking about deploying or employing a forestation technique, whether it be the billion-tree tsunami or the 10-billion-tree tsunami, I also think of that as part and parcel of this whole notion of climate engineering.

Another nature-based technique for which Pakistan has the potential for CDR is Biochar. In Biochar, charcoal is produced from plant matter and stored in soils to remove CO₂ in the soil. Pakistan, an agricultural country with sufficient experts, offers a good place for Biochar projects. An international oil company has partnered with a leading food and agricultural company to explore biochar as an emission removal option from Pakistan's Agricultural and forestry sector (Shell, 2022). In 2015 few scientists established “the biochar research group” to promote the research and development of biochar in Pakistan. The group's objective is to provide a platform where all researchers can share knowledge and benefit from the findings of researchers working in the field.

Compared to forestation and reforestation, DACCS is a technological approach. DACCS is a different technology than CCS, but the two have specific synergies. If there is a clear idea about CCS, we can know the potential of a country's DACCS. DACCS is a carbon removal strategy, while CCS is a carbon mitigation strategy (Batres et al., 2021). Initial research suggests that DACCS machines may be paired with the infrastructure of CCS, like cement or steel plants, as it will be economically advantageous (Batres et al., 2021). Asian Development Bank has conducted a study under Technical Assistance (TA) to assess the CCS potential of Pakistan. ADB suggests that no large-scale plant in Pakistan can be allocated for CCS due to unviable investment scenarios and fluctuation in the prices of CCS (ADB, 2019). However, if the conditions are favorable, these are addressable problems, possibly by China. It also indicates that CCS would likely happen first. Overall, Pakistan has good points for creating a synergy between DACCS and CCS (Rashid et al., 2020). ADB (2019) described its TA as a partial success because the government has less interest in it, and relevant stakeholders lack the appropriate knowledge of CCS. In Pakistan, several sites can support CCS, depending on the requirement. However, due to the weak economic situation, Pakistan must seek external assistance to execute any such project (Rashid et al., 2020). Pakistan's weak financial position can influence Pakistan's ability to choose nature-based CDR over technology-based carbon removal options.

Unlike forestation and afforestation, where huge land is required, DACCS requires a significant energy supply. Furthermore, two possible options exist to reduce the energy implications of DACCS. The first is to connect the DACCS with renewable energy resources, and the second is to identify storage sites with less environmental impact because of the transportation of DACCS (McQueen et al., 2020; Batres et al., 2021). Indirect and direct air quality impacts of technological CDR are some of the most significant gaps in information surrounding CDR, partly because few projects exist that can serve as examples to study. Because there is little public information on air quality implications, positive or

negative, it is not easy to empower communities to make decisions about scientific matters. The table below presents an overall situation of Pakistan's potential for CDR techniques. In Pakistan, the role of provinces is critical for the implantation of nature-based CDR because, after the 18th amendment in the constitution, forestry and land matters are primarily dealt with at the provincial level.

S.No	Technology for CDR	Pakistan's Physical Potential	Justification	Co-Benefits
I.	Afforestation and Restoration	High	Government Support and projects like the Billion Tree Tsunami (BTT) project	Biodiversity Improved soil health Flood and erosion control Economic benefits ⁴
II.	Restoring wetlands	High	Governmental Initiatives	Flood Protection, Water Quality, Fisheries, Recreation ⁵
III.	Biochar	High	Vast Agriculture base	Improved soil quality Energy production ⁶
IV.	Building with Biomass	Medium	Low Forest Cover	Economic development in rural areas ⁷
V.	Microalgal cultivation for Sequestration	Medium	Sufficient sunlight all over the year	wastewater treatment, harvesting, and the novel bio-products produced by microalgal biomass. ⁸
VI.	Carbon Sequestration in Soils	Medium	Lack of modern Agriculture techniques but vast agricultural land	Improved soil health Reduced fertilizer use ⁹
VII.	Direct CO ₂ removal	Low	High Energy, financial and Technological Requirements	Technology Transfer

Table 1: Pakistan's Geographical Potential for CDR

⁴ [Fact Sheet: Forestation | American University, Washington, DC](#)

⁵<https://www.bing.com/ck/a?!&&p=f1f1016bcf83b2e6JmItdHM9MTcwMjQyNTYwMCZpZ3VpZD0yZyEzTg4Mi02MGYyLTyxZTMtMjc4Yy1mYjY1NjE4YzYwYjlm aW5zaWQ9NTQ4OQ&ptn=3&ver=2&hsh=3&fclid=2712e882-60f2-61e3-278c-fb65618c60b2&psq=wetlands+cobenefits&u=a1aHR0cHM6Ly93d3cuZXBhLmdvdi9zaXRlcy9kZWZhdWx0L2ZpbGVzLzlwMjEtdEVEvZG9jdW1lbnRzL2Vjb25vbWlj X2JlbnVmaXRzX29mX3dlldGxhbmRzLnBkZiM6fjP0Zxh0PVdlldGxhbmRzJTlwY29udHJpYnV0ZSUyMHRvJTlwdGhJTlwbmF0aW9uYWwIMjBhbmQIMjBsb2NhbcUy MGvjb25vbWllcyxiZW5lZml0cyUyQyUyMHN1Y2gIMjBhcyUyMHBvbGx1dGlvbiUyMGNvbnRyb2wlMjBhbmQIMjBmbG9vZCUyMHBByb3RIY3Rpb24u&ntb=1>

⁶ [Fact Sheet: Biochar | American University, Washington, DC](#)

⁷ Hosen, M.E., Siddik, M.N.A., Miah, M.F. *et al.* Biomass energy for sustainable development: evidence from Asian countries. *Environ Dev Sustain* (2022). <https://doi.org/10.1007/s10668-022-02850-1>

⁸ Singh, U.B., Ahluwalia, A.S. Microalgae: a promising tool for carbon sequestration. *Mitig Adapt Strateg Glob Change* **18**, 73–95 (2013). <https://doi.org/10.1007/s11027-012-9393-3>

⁹ [Fact Sheet: Soil Carbon Sequestration | American University, Washington, DC](#)

In its revised NDC (2021), Pakistan has identified several approaches to mitigate carbon. It has become an active member of the carbon trading community, indicating a potential appetite for CDR in Pakistan. These initiatives include the carbon pricing instrument (CPI), forest carbon partnership facility (FCP), national committee on the establishment of carbon markets (NCEC), blue carbon ecosystem, adoption of cap-and-trade schemes, and carbon levies to manage industrial emission efficiency. Pakistan also aims to revive natural carbon sinks, maintain forest inventories, and increase capacity for monitoring and modeling carbon changes. The government of Pakistan has stated that:

The GoP has undertaken several policy measures since 2016 when the NDC was first submitted. The articulation and progress on ecosystem-based approaches, low carbon development, carbon sequestration, and adoption of renewable energy (RE), have all far exceed the narrative presented in the NDC (Pak-NDC, 2021, p. 13).

Technology transfer from China to Pakistan regarding CDR is a big incentive. “Pakistan will require finance, technology transfer, and capacity building in line with Article 4 of the United Nations Framework Convention on Climate Change (UNFCCC) (Pak-NDC, 2021, p 16-17). By developing a CDR program under the BRI, Pakistan can import the latest technologies for climate change management. Pakistan has acknowledged the role of technology-based interventions in managing climate change issues and sought support from the international community.

CDR projects have the potential to attract significant financial assistance and investment to BRI host countries, including Pakistan. China’s carbon trading scheme, which actively engages the private sector, offers an opportunity to channel investments into Pakistan’s carbon reduction initiatives. Expanding the scope of carbon offset mechanisms to include BRI partner countries could improve cost-efficiency, as Pakistan presents opportunities for lower-cost carbon offsets. Pakistan's recognition of emerging carbon markets is reflected in a statement by a federal Minister, who emphasized the country's commitment to global carbon credit markets: *“to capture the global carbon market, Pakistan partners with a greenhouse gas crediting programme”* (Sherry Rehman, July 11, 2023). As a developing nation heavily dependent on international financial assistance for environmental initiatives—particularly mitigation and carbon removal—Pakistan stands to benefit significantly from leveraging these financial mechanisms. This alignment is further reinforced in Pakistan’s NDC, which states:

Having considered the existing potential for mitigation in the country, Pakistan intends to reduce up to 20% of its 2030 projected GHG emissions, subject to the availability of

international grants to meet the total abatement cost for the indicated 20 percent reduction amounting to about US\$ 40 billion at current prices. Pakistan's adaptation needs range between US\$ 7 to US\$ 14 million/annum during this period (Pak-NDC,2016, 24).

Countries like Pakistan often face pressing development priorities that can constrain their ability to fully commit to ambitious climate actions in the short term. While Pakistan and other BRI member countries might initially exhibit limited interest in CDR as a standalone climate solution, they could find significant traction in adopting CDR due to its multiple co-benefits. Climate strategies—whether adaptation, mitigation, or CDR—contribute to broader goals, including improved public health, enhanced energy and food security, biodiversity conservation, ecosystem restoration, and sustainable development (IPCC, 2023). However, the realization of these co-benefits depends heavily on factors such as the chosen method, scale, and site selection for CDR implementation (IPCC, 2023, p.54).

Pakistan's large-scale 10 Billion Tree Tsunami Project (TBTP) exemplifies its openness to nature-based solutions for carbon removal while simultaneously addressing socio-economic challenges. This initiative not only aims to increase forest cover but also serves as a significant employment generation mechanism. The government reported creating 85,000 jobs by engaging unemployed community members in tree nurseries and sapling care, with plans to expand employment opportunities to 200,000 people to support ongoing afforestation efforts (Farand, 2021). Such projects underscore Pakistan's willingness to integrate climate action with developmental priorities, highlighting the potential for further exploration of CDR initiatives that align with national goals.

It seems Pakistan is seriously considering moving one component of its economy towards green jobs and attracting foreign investment or aid under its green Pakistan activity. Pakistan is designing financial products through which it (Pakistan) can retire its debt owed to Western countries and multilateral organizations in return for nature restoration activities (Farand, 2021). It is equally vital in the case of BRI as there is a possibility that China may consider debt-for-nature swaps building a green BRI (Yue & Wang, 2021). According to an estimate, developing countries owe Chinese lenders \$ 1.1 trillion (McCarthy, 2023). There is a possibility that:

Some developing countries might consider such investments salutary if they believe that the investments could prevent serious climatic impacts, many of which will disproportionately affect such states. In the context of article 9, this could facilitate developed-country parties' financing of CDR projects in developing countries as part of their obligations to effectuate mitigation (Craik & Burn, 2016, p 10-11).

China occupies a unique position in global climate finance, straddling the line between the global South and an emerging economic powerhouse. In international climate negotiations, China aligns itself with developing nations, advocating for equity and differentiated responsibilities. However, its rapid economic and industrial growth has led developed countries to call for China to take on a greater share of climate finance responsibilities. Despite this pressure, China has so far been reluctant to fully embrace this role, maintaining its stance as a developing nation (Patel, 2024).

Mangroves are among the most effective tools for Payments for Ecosystem Services (PES) programs, offering incentives for forest conservation (Hamilton & Friess, 2018). Known as "blue carbon" ecosystems, mangroves have an exceptional ability to sequester carbon. Per unit area, they can store up to four times more carbon than terrestrial forests. These ecosystems consist of a tangled mix of trees and shrubs thriving in coastal waters across tropical and subtropical regions. Their elongated roots, visibly jutting out of the water, anchor themselves firmly in loose, muddy soils (Mcsweeney, 2019).

Unfortunately, mangroves are often cleared for activities like commercial fishing, significantly diminishing their carbon absorption capacity. However, unlike global trends, Pakistan has made commendable progress in mangrove conservation and expansion. The mangrove cover in Pakistan increased from an estimated 477.22 km² in 1990 to 1,463.59 km² in 2020, reflecting an annual growth rate of 3.74%. Moreover, mapping results indicate an enhancement in mangrove tree canopy density (UNEP(B), 2021). This achievement positions Pakistan as a success story in nature-based carbon sequestration efforts.

CDR is emerging as a key climate policy option, but its governance remains in its early stages. Many rules and principles surrounding CDR are still under development and remain subject to debate and contestation (Craik, 2023, p. 22). This lack of established governance frameworks creates an opportunity for developing countries like Pakistan to actively participate in shaping these rules. A consensus between China and host countries of the BRI, including Pakistan, on CDR principles and policies could have far-reaching impacts on global environmental governance, particularly given the influential role of the G77+China bloc in international climate negotiations.

In conclusion, the BRI is gradually transitioning towards greener solutions, incorporating climate finance as a central element. CDR represents a significant pillar in this greening effort, offering Pakistan valuable opportunities for economic benefits, technological cooperation, and ecosystem services. Nature-based CDR solutions, such as BECCS, align with Pakistan's ecological strengths and

policy priorities. However, the question remains whether the BRI can facilitate a "just CDR" framework, particularly in a Senian sense—addressing equity, fairness, and developmental capabilities. To answer this, it becomes essential to apply a capability approach to evaluate the extent to which the BRI can deliver inclusive, equitable, and sustainable CDR outcomes for countries like Pakistan.

A Framework for Just CDR Under the BRI

The capability framework does provide a theoretical foundation to imagine a scenario for a just CDR and also analyze its benefits, agency, and betterment that CDR can bring for humanity. CDR schemes need to be designed through which developed countries (and China) discharge their historical obligations in carbon removal for the greater good of humankind and attainment of the Paris Agreement and not for future ambitious industrial activities (Batres., 2021). BRI currently provides technical and financial mechanisms for CDR partnership between the BRI and China host countries but ensuring climate justice appears challenging. First, the capability framework can help analyze CDR for protecting and advancing human capabilities instead of merely looking at CDR as an environmental policy. According to Sen:

Recent discussions have rightly emphasized the threat that the environment faces today, but there is a need for clarity in deciding how to think about environmental challenges in the contemporary world. Focusing on the quality of life can help in this understanding and shed light not only on the demands of sustainable development but also on the content and relevance of what we can identify as environmental issues (Sen, 2009, p. 248).

Attaining a sustainable environment and pursuing low-carbon development can be seen as a freedom that developing countries have a right to pursue. Addressing climate change can benefit human well-being and ecosystems (IPCC,2023). The capability framework asserts that freedom of any kind is linked with other freedoms like social opportunities, enhancing economic freedom, and strengthening social opportunities (Sen, 1999, p. 10-11). The capability framework for a just CDR governance has four key elements: objective, processes, governance, and outcome, and each key element is further classified into three sub-elements.

Objective

Thriving human capabilities and a sustainable environment are interlinked, and CDR as a climate policy option must support this objective. Anthropogenic climate change threatens sustainable

development, human well-being, and the physical security of the people and the infrastructure. The first objective of the framework is to attain human well-being by removing carbon emissions. CDR needs to address the core of the climate change issue: the existence of carbon in the atmosphere. Global carbon emissions and retention lead to an increase in global average temperature. By removing the carbon, CDR may protect, and advance human well-being threatened due to carbon present in the atmosphere. The capability of human beings to do something constructive is impacted by variations like age, location and temperature, droughts, and heat waves (Sen, 1999, p.88). This way, CDR can address some of the variations that are directly linked with carbon existence in the atmosphere.

Moreover, ensuring low-carbon development as committed under the Paris Agreement will be a difficult and long path for many developing countries, especially in sectors like agriculture, infrastructure development, energy and transportation. This inability to attain low-carbon development in developing countries can create a sense of deprivation. The sense of inequality may also erode social cohesion, and some inequalities can make it difficult to achieve even efficiency (Sen, 1999, p.93). Decarbonizing the economy is crucial for developing countries like Pakistan because it is part of their NDCs under the Paris Agreement and can help developing countries create green economies. Developing countries want to present themselves as green nations and protect their trade partnerships with developed countries (Ebrahim, 2021). Pakistan faces a tough choice between its domestic energy needs, limiting the increase in global average temperature, and emission reduction responsibilities under the Paris Agreement.

Development is fundamentally an empowering process, and this power can be used to preserve and enrich the environment, and not only to decimate it. We must not, therefore, think of the environment exclusively in terms of conserving pre-existing natural conditions, since the environment can also include the results of human creation. For example, purification of water is a part of improving the environment in which we live. The elimination of epidemics contributes both to development and to environmental enhancement (Sen, 2009, p.249).

A just CDR can offer low-carbon development and financial incentives to developing countries. Due to land and labour costs, CDR initiatives in developing countries are likely cheaper than developed ones. Sen also highlights this peculiarity of developing economies and suggests that developing countries are in a better position to offer some services that otherwise cost more in developed

countries (Sen, 1999, pp.47-48). We have witnessed in the case of the clean development mechanism (CDM) that developing countries offered land for carbon credits while developed countries made financial and technical contributions. Developing countries like Pakistan can host CDR projects for their domestic carbon removals and on behalf of developed countries and their wealthy corporation. Furthermore, CDR partnerships between host countries can be analyzed to ensure protective security for poor people. These low-carbon projects related to infrastructure and energy can protect poor people against starvation by creating economic opportunities and providing constant energy enhancement. The capability framework supports inclusive development by treating a sustainable environment as essential to human security and protecting capabilities (Gasper, 2020). This synergy between CDR and the capability framework suggests that CDR can be explored as a development under the BRI. According to an estimate, BRI-related projects can help lift more than 110 million people out of poverty (Maliszewska & van der Mensbrugghe, 2020). Including CDR in BRI can make BRI a green and low-carbon transnational project. There is a need to acknowledge that pursuing low-carbon development is an act of human well-being and helps reduce the temperature in the long run (Li & Chen, 2021). A relationship between human well-being and carbon emissions (and also removal) can be understood through the demand and supply of energy.

On the one hand, the level of human well-being depends on the satisfaction of their own needs and energy consumption is often the strong support behind it. On the other hand, energy consumption is also the main source of carbon dioxide emissions, including carbon emissions generated by the direct energy consumption of residents, such as heating, cooling, lighting, cleaning, cooking and indirect energy consumption caused by the consumption of products and services. Therefore, to some extent, the relationship between human well-being and energy consumption reflects the relationship between human well-being and carbon emissions (Li & Chen, 2021, p.6).

One of the key components of the BRI is establishing energy projects in the host country; this way, BRI addresses the issue of human well-being. However, most of these energy projects (coal power plants) are increasing carbon emissions in the host countries, which means that human well-being under the BRI would be limited without carbon reduction or removal of these energy projects. BRI is primarily an investment forum that does not directly endorse the kind of development envisioned in the capability framework but focuses more on infrastructure that is carbon intensive. Primarily, BRI aims to promote investment and trade partnerships in the host countries. However, due to its transactional nature, the BRI approaches environmental sustainability in the host countries from the

host countries' perspective and not as a fiduciary duty for China. Along with financial and technical cooperation with host countries of primary importance, CDR can also help attain low-carbon development.

Initiatives like greening the BRI provide a platform for exploring CDR, for low-carbon development for developing countries. Developing countries like Pakistan could host CDR projects for their domestic carbon removals (increased due to the BRI) or on behalf of China to generate carbon credits. Due to low land and labour costs, emissions reduction and removal projects can be easily initiated in developing countries like CDM projects.

A poor economy may have less money to spend on health care and education, but it also needs less money to spend to provide the same services, which would cost much more in the richer countries. Relative prices and costs are important parameters in determining what a country can afford (Sen, 1999, pp.47-48).

The benefits of CDR can lead to energy and economic security. The concept of human security under the capability framework tells us to secure people's basic needs (Gasper, 2020). The host countries of the BRI look at the BRI as a source through which economic and energy security can be attained. BRI promotes the well-being and development of people in poverty by promoting low-carbon development, creating green economies, and protecting people from food and energy insecurity. The sub-goal of protective security in the CDR aligns with the Chinese national goal of peaking its emissions by 2030:

We (China) must keep national energy security and economic development as the bottom line, strive for time to realize the gradual replacement of new energy, and promote the smooth transition of energy low-carbon transformation. We will take concrete steps to safeguard China's energy security, food security, and the security of industrial and supply chains and to keep ordinary citizens living and working as normal (NDRC,2021).

China's long-term emission reduction strategy, aligned with the Paris Agreement, suggests a substantial reliance on CDR technologies by the mid-to-late 21st century. As part of this trajectory, China may also consider exporting these technologies to BRI partner countries. This approach would not only reinforce China's commitment to global climate goals but also position the BRI as a sustainable and environmentally responsible transnational development framework.

By integrating CDR technologies into BRI projects, China can address multiple objectives: reducing carbon emissions, stimulating economic growth, and enhancing environmental resilience in partner nations. Beyond environmental benefits, such initiatives have profound human development implications. Protecting against starvation, severe environmental shocks, and socio-economic deprivation while simultaneously creating new economic opportunities can significantly enhance human capabilities. This aligns with the principles of sustainable development, ensuring that environmental stewardship contributes directly to improving well-being, resilience, and economic

Processes

The process stage evaluates whether the existing system under the BRI can facilitate open, transparent, and locally sensitive decision-making. Current observations suggest that this remains unlikely in its present form, as both the BRI and the CPEC appear largely top-down, shaped by national agendas with limited visibility of mechanisms for local consultation or meaningful democratic participation beyond the national level. However, the non-conditionality principle underlying the BRI offers a positive dimension. Unlike traditional development assistance, the BRI does not impose external priorities but operates through more transactional arrangements. This transactional nature creates potential opportunities for CDR development, where both China and host countries can benefit through credit generation and shared co-benefits. Technologies such as BECCS and DACCS are particularly well-suited for these transactional partnerships. Additionally, the structure for science and technology cooperation within the BRI is a crucial factor. Effective collaboration frameworks could enhance the deployment and scalability of advanced CDR technologies, ensuring mutual benefits for China and partner countries while addressing broader sustainability goals.

Regarding processes for CDR initiatives, the capability approach enshrines three principles: processes should be democratic, parties must exercise informed consent and finally, the provision of free agency. All these points at the processes stage are meant to reduce deprivation and give more voice to stakeholders with diverse backgrounds. The use of instrumental freedoms, such as the opportunity for open discussion, public scrutiny, electoral politics, and uncensored media, significantly supports the process of preventing famines and other crises (Sen, 1999, p.188). In addition to that, CDR may be applied to different environmental issues in different countries as a climate policy option. For some countries, CDR might be an option to attain clean energy; for others, it could be a source of sustainable agriculture. Due to their vulnerability in the wake of climate change and limited financial and technological resources, developing countries could also approach CDR as a potential revenue

generation tool through the carbon market and trade. An interviewee (A) stated that while analyzing CDR potential, it is important to remember that "the countries are also different, very much in terms of how well they take care of their population and how democratic they are." The democratic processes can help policymakers contextualize and indigenize CDR research policies for a particular country. The capability approach stresses that a country's context and situation matter in evaluating public policy choices (Sen, 1999, p.127). For example, countries with a large part of the land may prefer agriculture-based CDR, while countries with vast coastal lines may search for sea-based CDR interventions. Developing countries' active role in formulating CDR policies would be further strengthened by structuring CDR policies through public participation. According to the capability framework:

The question is not only closed, it must be wide open for people in the society to address and join in deciding. An attempt to choke off participatory freedom on grounds of traditional values (such as religious fundamentalism, or political custom, or the so-called Asian values) simply misses the issue of legitimacy and the need for the people affected to participate in deciding what they want and what they have reason to accept (Sen, 1999, p. 132).

The debate about the viability of CDR as a climate policy option in developing countries would inform people about the issues and help them exercise their free will and agency in the decision-making processes. Informed consent can only be exercised if there is capacity building in the participating countries. An essential aspect of the democratic process is that it helps people to increase their knowledge and engage in informed discussion (Sen, 2009). Once the democratic process and informed consent are ensured, the process's final stage is to exercise free will. Sen believes free agency is a core part of the development processes and strengthens other capabilities (Sen, 1999, p.6). It means that host developing countries must freely exercise their free will while accepting, rejecting, or determining the type of CDR they want to pursue.

Regarding the processes stage, the capability framework outlines three elements: democratic processes, free agency, and informed consent. Democracy means the local host country and the local population have a significant voice and deliberation during the decision-making of CDR initiatives. The democratic process ensures that sensitivity to local context matters. For example, nature-based techniques like afforestation have implications for land use, while technological approaches like DACCS have significant energy requirements (CBD, 2016). These peculiar implications of CDR techniques may have social and governance implications for the area where CDR projects are planned.

Without the active participation of local communities, it will be hard to move forward with CDR projects in countries like Pakistan. In some cases, CDR deployment requires vast land, which could be challenging in some developing countries as the forests are more than just carbon sinks in some parts of the world (Nijnik & Halder, 2013). It is because a large population relies on these forests for their livelihood. For the sustainability of the CDR techniques, the role of local communities is critical because policies are made at the national level but implemented locally. An example is South Asia, where the land is labeled as “mother-earth”, as it feeds human beings and has an emotional and spiritual place within the lives of ordinary citizens. Therefore, for any large-scale deployment of afforestation or BECCS techniques, policymakers would have to consider these sentimental attachments of the people to their land. These human rights issues may have further political implications, leading to political tensions and demands for governance reforms (Honegger et al., 2018). CDR’s feasibility can be increased by developing a portfolio of options under CDR rather than deploying a single option at a vast scale (Rueda et al., 2021). A long-term and multidimensional strategy is required to minimize the harmful effects of CDR and ensure the permanent removal of carbon.

An open discussion is crucial regarding democratizing the CDR processes in the host countries. The BRI has a top-down model in which the Chinese national government interacts and finalizes development plans with the national governments of the host countries. There is very little room for open discussion, especially for local governments and indigenous communities, which appears to be contrary to the demands of Sen’s model of justice. However, China may acknowledge and accommodate the concerns of national governments, but BRI governance does not appear to accommodate the concerns of local communities (Loh et al., 2023). This aspect of BRI contradicts Sen’s idea of participatory democracy through which Sen argues for the engagement of local stakeholders. For making the CDR initiative a success story, the role of local communities is crucial.

Adequate financing mechanisms and capacity building are at the core of informed consent. The large-scale deployment of CDR needs vast resources, which is challenging for developing countries because of their limited financial and technical capacity. The Paris Agreement explicitly supports technology transfer initiatives for meeting NDCs. Under the BRI, there seems to be limited technology cooperation, that too is institutionalized at the state level. The lack of transparency has seriously hindered developing countries from fully optimizing the potential of technological innovations, as they cannot access the inner workings of a technology (Batres et al., 2021). Developing countries

usually become technology customers, but they cannot fully internalize a technology because of a lack of knowledge transfer from developed to developing countries. The study Informants believed that the future of approaches like CDR depends on technology transfer. However, the informants' key concern was whether developing countries could offer expert opinions about CDR if they do not have access to technology. An interviewee (A) stated:

Global south societies have the possibility today to leapfrog and bring about change very quickly. So, if you look at the 2030 development agenda, 2030 is not far away. It is not just about nine years now, but it is possible if we have a better sharing of technologies, and this should be a very important topic in the global climate negotiations. How can technologies be provided to developing countries, particularly to manage change and to bring about success in managing the targets that have been set in 2030?

Providing informed consent under the capability framework also means that the host countries have the technical and financial capacity to make an informed decision concerning CDR. For China, technological expansion and transfer could help to establish China as a market leader, setting standards for others in specific fields, e.g., 5G and high-speed rail (Ivelva, 2019). Developing countries emphasize knowledge and technology sharing in global climate negotiations as the Paris Agreement contains relevant provisions (Interviewee-A). The country or group of countries facilitating knowledge sharing of CDR research in developing countries will likely have a more significant say in designing the CDR governance. This relates to who benefits or whether CR projects can be designed to meet Pakistan's or the local community's development aspirations or capabilities. In the case of CDR, Pakistan will likely be more concerned about the smooth provision of technology and finance instead of sponsoring the country, whether China or the USA (Interviewee-B). However, because the BRI is already in process and China is keen to make BRI a knowledge-sharing platform, host countries of the BRI, like Pakistan, will likely be exploring CDR technology and knowledge-sharing options under the BRI. An Interviewee (C) stated:

Technological transfer and kind of technical standards are a big part of the BRI. So basically, this expanding technological standards from China to other countries is definitely part of influence strategy of China together with political influence and economic influence.

One potential research and governance platform for CDR under the BRI is the Alliance for International Science Organization (ANSO). The ANSO initiative of the Chinese Academy of Science has support from

almost 36 member countries of BRI. ANSO has been established for scientific cooperation, research and knowledge sharing within the BRI. The vision of the ANSO is to:

To become an international science organization of global impact in catalyzing and implementing concrete innovative programs, initiatives and actions in science, Technology, Innovation and Capacity Building (STC) for the promotion of shared development and the advancement of the UN Sustainable Development Goals (SDGs) (ANSO, 2023)

Then there are some specific Chinese initiatives about carbon management which can also help host countries of the BRI concerning CDR. For example, China has launched a global Carbon dioxide monitoring satellite that successfully detected humanly caused carbon emissions in the atmosphere and the existing situation of carbon sinks (CAS, 2022). The scientists working on this project have expressed satisfaction with the project's progress. They hope these technological advancements will play a crucial role in attaining carbon neutrality in the long run for China (CAS, 2022). This technological capability of China for measuring anthropological carbon emissions can be a good facility for partnering countries of the BRI. This technology may help China's MRV of CDR projects in the host countries.

The third element of the capability framework for CDR at the processes stage is free agency. Large-scale CDR projects can affect the countries' social and economic governance. Developing countries may have different priorities and place certain conditionalities for executing CDR projects on their soil. Developing countries may like to explore CDR for research and understanding purposes while pursuing adaptation as a primary climate policy option. For example, as reflected in its NDC, Pakistan's emission targets suggest that Pakistan is willing to cut its domestic emissions, but that is attached to several conditionalities. First, Pakistan considers adaptation as its primary objective and not mitigation. An interviewee (B) argued that "I think Pakistan should be more focused on climate change adaptation because, as one of the countries that are producing a very, very minimal amount of greenhouse gases." This stance highlights the relevance of co-benefits that address adaptation, especially nature-based solutions in developing countries like Pakistan. BRI's governance structure suggests that China values host countries' input in environmental decision-making regarding BRI projects. Therefore, countries with solid environmental governance have a brighter chance of implanting their agendas on projects (including CDR), and countries with weak environmental governance are likely to have less margin to negotiate for climate cooperation under the BRI. One key strength of the Chinese development initiatives is that, unlike Western development partnerships,

which ignore domestic scenarios, Chinese institutions adopt policies according to local or host countries' circumstances (Adeney & Boni, 2021, p.21). For example, countries like Pakistan, which faced an energy crisis, have successfully received Chinese financial and technical assistance in the energy sector. BRI primarily consists of developing countries, most of which are also members of G77+China³ in climate change negotiations. This way, the host countries of the BRI can easily negotiate CDR cooperation with China, but only if developing countries are willing to explore CDR.

Institutions/Governance

The key governance issues surrounding CDR under the BRI revolve around fiduciary duty and whether China might feel an obligation to enhance Pakistan's climate outcomes by offsetting increased emissions generated through its investments. Additionally, the BRI's institutional structure may offer some space for self-governance. China appears disinclined to dictate environmental or social policies to partner countries, maintaining a transactional rather than prescriptive approach. While CDR remains primarily a country—or region-specific climate policy tool, its governance challenges often carry transnational implications. Critical questions arise: Who will govern CDR projects, and who bears responsibility if something goes wrong? These questions are central to the legitimacy and effectiveness of CDR governance frameworks. Furthermore, CDR is a cost-intensive approach that requires economic feasibility and technological accessibility for developing countries to be widely implemented.

As part of the fiduciary duty, developed countries or sponsors of transnational development projects could play a significant role in creating social, economic, and technological opportunities that empower developing nations to undertake effective CDR initiatives. The capability approach underscores the importance of self-governance, emphasizing that host countries must have a leading role in overseeing and directing CDR projects. This framework also provides guidance on addressing liability concerns, mitigating discriminatory practices, and ensuring fair outcomes for all stakeholders involved.

Historically, developed countries' policies have often disadvantaged vulnerable communities, perpetuating systemic inequalities (Sen, 1999, p.15). In the context of CDR governance, the capability approach's concept of "neighbourhood", can be of use which highlights the interconnected nature of sustainable development. One country's progress depends on another's sustainable advancement, and fiduciary duty emphasizes the responsibility that developed or investing nations have toward developing countries in ensuring fair, transparent, and inclusive CDR governance.

There is a long history of attempts to go beyond the positional confinement of our moral concerns to the proximate 'neighbourhood,' resisting the relational vision that something is owed to one's neighbours that is not, in any way, owed to people outside the neighbourhood. The question of one's duty to one's neighbours has a huge place in the history of ethical ideas in the world (Sen, 2009, p. 170-171).

Once developing countries acquire the knowledge, technology, and resources needed to pursue a low-carbon development path, they cannot solely attribute their challenges to a lack of support from developed countries. The principle of fiduciary duty encourages nations to move beyond parochialism, fostering an understanding of the cultures, values, and circumstances of other societies and communities (Sen, 1999, p. 244). The capability framework remains optimistic that, despite inherent limitations, the capitalist model can operate ethically and leverage its institutions to address global challenges effectively (Sen, 1999, p. 263). As interviewee B highlighted, "It should be the developed world that pays for it (CDR) and ideally pays for it heavily due to their role in the climate crisis to begin." This principle of fiduciary duty extends to countries like China, which sponsor transnational development projects primarily in host countries from the global South. By embracing this responsibility, sponsoring nations can ensure that carbon dioxide removal initiatives are implemented fairly, equitably, and with consideration for the unique developmental needs of their partner countries.

The idea of an impartial spectator in the capability framework addresses monitoring reporting and verification (MRV) in CDR governance. CDR 's transparent reporting, verifying carbon sequestration, and its permanence are crucial (Craik & Burns, 2016). According to the capability approach, transparency is vital for creating an environment of openness and trust under which all stakeholders can deal with each other (Sen, 1999, p.39). This transparency can be ensured by creating specific laws about transparency or inculcating a sense of obligation amongst the stakeholders (Sen, 1999, pp. 267-268). Sen argues for having an impartial spectator to monitor and govern the transparency and trust issue. The capability approach places great emphasis on trust and transparency to ensure effective transactions in the governance of any system.

The capability framework outlines three governance elements for CDR governance in the host countries of the BRI: self-governance, fiduciary duty and impartial spectator. China's greening of the BRI is a notable initiative that can provide governance for CDR in the host countries. However, for effective environmental governance initiatives (including CDR), the capacity of China and the host

countries will matter (Coenen et al., 2019). To better analyze BRI as a governance forum for CDR projects in the host countries, it is crucial to understand the critical governance debates about CDR, as certain governance issues are associated with CDR. Concerning CDR, the interviewees broadly discussed two types of concerns. The first concern interviewees shared about CDR is the moral hazard aspect of emerging climatic technologies. An interviewee (B), while elaborating on the concept of moral hazard, stated that:

There is this whole notion of moral hazard that's attached to it. And that primarily alludes to the fact that if we start talking about these technologies and particularly geoengineering, then how are we going to get the Aramco's and Shell and Saudi Arabia and China and USA and India? These countries and these corporations are the largest emitters to stop doing what they are doing and focus on a cleaner future. Because the moral hazard argument goes that if it is perceived that there is a potential solution out there, it will stop the policymakers and decision-makers from taking action right now.

Therefore, self-governance in the capability framework can guide the host countries to design the CDR governance under the BRI according to their local needs. Autonomy or self-governance is entirely in line with the capability approach. Self-governance for CDR initiatives means the host countries of the BRI are fully involved in designing and executing the CDR projects. As CDR can make many changes to local governance and environmental policies, self-governance is vital. Acceptance of change is inherently complicated, especially in areas like climate change, where stakes are so high between developing and developed countries (Interviewee- (A)). A few technologies in CDR, like DACCS and BECCS, have some social challenges that need to be discussed to determine their viability for different cultures and societies (Honegger et al., 2018; Fuss et al., 2016; Lin et al., 2018). These ethical concerns about CDR highlight the importance of governance tools like MRV and transparency. Transparency is crucial as there are concerns about BRI's ability to ensure transparent governance of the projects in the host countries (Hillman, 2019). Therefore, interviewees wanted to explore the option of CDR while ensuring transparency and precaution. An interviewee (B) stated that "anything that happens in this regard should ideally be out in the public domain. It should be discussed openly... any decision in this regard should also be done in a collaborative manner." Given South Asia's peculiar nature and geopolitical dimension, the interviewees emphasized the need for transparency in CDR governance. An important question is what type of CDR will be promoted by BRI as CDR may be applied to different environmental issues in different countries as a climate policy option. The flexibility of BRI can support

almost all types of CDR, which aligns with the circumstances of the host countries. The structure of the BRI is such that host countries of the BRI have a significant role in the execution of environmental governance, but it all depends on their domestic circumstances and governance style. In countries like Pakistan, with weak environmental regulations but Chinese solid political and financial influence, the chances of effective environmental governance are thin (Coenen et al., 2019). Therefore, BRI offers a self-governance option for CDR projects to the host countries.

An essential component of CDR governance is who will fund CDR projects and bear responsibility if something goes wrong. The fiduciary duty under the capability framework means the sponsoring country of CDR takes financial responsibility and bears liabilities for CDR projects executed on the soil of the host countries. The deployment of CDR technology that is consistent with 2 °C requires significant financial allocation. Although large-scale (CDR) is not likely to be deployed at full scale till 2050, CDR research requires significant financial support (Craik, 2023). There is a possibility that developed countries may divert their climate finances from mitigation to CDR projects under Article 9 of the Paris Agreement (which relates to the provision of finance from developed countries to developing countries); however, only a few developing countries with a climate urgency will endorse this move (Craik & Burns, 2016). In the case of developing countries, the concept of respective capabilities is vital as developing countries will rely on external financial and technical assistance (Hubert, 2018). CDR can be more attractive for developing countries if it is cost-effective and there is financial support from the sponsoring countries. That is the reason that to become acceptable as a climate policy option, CDR research must focus on cost reduction, monitoring, and verification mechanisms (NAP, 2018).

An example is SCS, an attractive technique because it is cost-effective and does not require significant land-use changes (IPCC, 2018). The cost of any climate policy option, especially CDR, is crucial for developing countries. In this situation, the BRI can offer an opportunity to access finances and capacity building for projects like CDR under the greening of the BRI initiatives. On the financial side, China has created the Green Silk Road Fund and South-South environmental cooperation. Another is the adoption of Green Investment Principles (GIP) for Belt and Road Development, which aim to provide standardized financial instruments for greening BRI across all the projects in almost all countries (Carey & Ladislav, 2021, p.9). The role of credits or International Transferred Mitigation Outcomes (ITMOs) may motivate China to support CDR elsewhere.

The impartial spectator means that the execution of CDR is monitored and validated by a neutral observer. BRI, the sponsoring apparatus for CDR projects in the host countries, has limitations in acting as a neutral observer and providing oversight for CDR projects. Most of the BRI is structured on bilateral agreements between China and the host country, and there is a dearth of independent bodies within the BRI that can provide neutral oversight for projects like CDR. Due to this reason, for CDR projects in the host countries, BRI can generate data and information but validating and monitoring of CDR doesn't seem feasible under the BRI. UNFCCC can validate the authenticity of CDR's initiative as an impartial spectator. In this area, specific provisions of the Paris Agreement and previously agreed-on mitigation mechanisms under the UNFCCC, like CDM, can offer some governance support (Craik & Burn, 2016; Honegger et al., 2021). An interviewee (A) pointed out that "both the UNFCCC and the regional institutions will have to be even more active because it (CDR) has to be tackled at the regional level." This regional aspect of CDR governance highlights the bottom-up approach used in the Paris Agreement. The submission of NDCs during the Paris Agreement has highlighted the importance of circumstances of countries that may play a crucial role in shaping the governance of climate policy options like CDR. The bottom-up approach indicates that countries may appreciate global climate goals but will structure their responses according to domestic circumstances. A notable initiative is the establishment of a BRI International Green Development Coalition (BRIGC) (Lew et al., 2021, p. 61; Carey & Ladislav, 2021). BRIGC has been created to unite the member countries against the common challenge of climate change, harness the best possible expertise from each member country, and work together towards the 2030 Agenda for Sustainable Development (UNEP, 2019). BRIGC has identified ten thematic areas for working together, which are (i) Biodiversity and Ecosystem Management, (ii) Renewable Energy and Energy Efficiency, (iii) Green Finance and Investment, (iv) Improvement of Environmental Quality and Green Cities, (v) South-South Environmental Cooperation and SDGs Capacity Building (vi) Green Technology Innovation and Corporate Social Responsibility (vii) Sustainable Transportation (viii) Global Climate Change Governance and Green Transformation (ix) Environmental Laws, Regulations and Standards and (x) Environmental Information Sharing and Big Data. These steps from China reflect the growing sensitivity of the Chinese policymakers to make the BRI a climate-friendly project for the host countries. Even if China and the host countries pursue some of these initiatives, it can enhance the capacity of countries to explore more complex climate policy options like CDR.

Outcome

Justice lies at the heart of this aspect of the case study. The objective is to determine whether a carbon dioxide removal (CDR) initiative under the Belt and Road Initiative (BRI) has meaningfully contributed to advancing environmental justice. In this context, China can be viewed as having obligations due to its role in facilitating increased emissions while simultaneously benefiting from the arrangements under the BRI. A key question arises: what should be the intended outcome of a CDR initiative, and what criteria should be used to measure its success? The capability approach emphasizes that the ultimate outcome of any initiative should be to enhance justice. In the case of CDR, success must be assessed through its contribution to climate justice, as the rising levels of carbon emissions in the atmosphere are fundamentally a climate justice issue. Developed countries have historically been the largest contributors to global carbon emissions, and removing or reducing carbon is a step towards addressing this imbalance and mitigating climatic injustice. One critical element aligning CDR initiatives with justice under the capability framework is the emphasis on a remedial and incremental approach to achieving justice. While carbon removal through CDR might address only a fractional aspect of climate injustice, every contribution matters within this framework. Sen underscores the significance of these incremental steps, arguing that even partial improvements are meaningful in advancing justice and addressing systemic imbalances.

But in dealing with the task of advancing justice through the removal of radical cases of injustice, even when there is no hope of achieving perfectly just institutions (or even any agreement on what they would be like), we can have much use for what has been dismissively called 'merely a partial order ranking' (Sen, 2009, pp.266-267).

Reducing climate injustice by removing carbon under the capability framework depends on participatory and intergenerational justice. More participation of developing countries to protect future generations from the harms of climate change reflects the spirit of the outcome under the capability framework. Historically, developing countries have remained passive actors or recipients of foreign policies in global environmental governance. The capability framework appreciates that famine victims become active agents in formulating policies concerning them instead of passive recipients of government support programs (Sen, 1999, p. 178). It is participatory justice that Western scholars sometimes ignore while discussing CGE governance, as they tend to focus more on distributive justice (Hourdequin, 2018). In CDR projects, the developing countries will be active agents in carbon removal policies instead of passive agents.

The informational base for evaluation must be regarding advancing human capabilities. For example, a CDR initiative can be evaluated in its outcomes using an appropriate informational base devised for human capabilities and development, i.e., SDGs. SDGs are often cited as a parameter concerning measuring human development. Measurement of human development was pioneered by Mahboob ul Haq, which Sen has endorsed in terms of its proximity to the capability framework (Sen, 1999). On the other hand, the eyes of mankind can provide a rational and neutral tool to determine the outcome of the CDR initiative under the capability framework and their success or failure in advancing human capabilities. According to Sen, “assessment of justice demands engagement with the ‘eyes of mankind’ (Sen, 2009, p.130). By relying on the eyes of mankind, a CDR initiative should be evaluated on how it has benefited humanity and not a particular country.

The capability framework for CDR emphasizes three key outcomes at the final stage of a project: enhanced justice, an improved informational base, and a broader perspective that considers global well-being. In the context of CDR under the BRI in Pakistan, these outcomes are particularly relevant given the country’s development priorities and environmental vulnerabilities. For CDR initiatives to succeed, carbon removals must be real, permanent, and sustainable, aligning with international standards and norms shaped by frameworks like the Paris Agreement (Craik, 2023).

Under the capability approach, incorporating these norms into environmental governance should aim to enhance justice and reduce climate injustice. Historically, developing countries, including Pakistan, have argued that developed nations must take responsibility for the environmental damage caused by the Industrial Revolution. CDR projects under the BRI must avoid reinforcing existing inequalities where the global North pursues its interests at the expense of the global South (Healey et al., 2021; Batres, 2021).

In Pakistan, challenges such as land scarcity, competing developmental priorities, and resource constraints may complicate the equitable implementation of CDR initiatives. Similar to concerns raised in developed countries like Singapore and Switzerland (Chalecki, 2021, p. 115), the transactional nature of BRI partnerships raises the risk of carbon imperialism. There is a possibility that Pakistan could offer its land and resources for CDR projects in exchange for financial incentives, ultimately benefiting external stakeholders rather than addressing domestic developmental and environmental priorities. To prevent such outcomes, CDR projects in Pakistan under the BRI must be designed with transparency, local consultation, and long-term sustainability in mind. Policies must ensure that the benefits of carbon removal are shared equitably, contributing to Pakistan’s national

climate goals and improving local communities' well-being. If implemented thoughtfully, CDR initiatives have the potential to address climate injustice, enhance environmental governance, and create pathways for sustainable development in Pakistan.

To determine and measure enhanced justice, a robust informational base is essential. The reduction of CDR under the BRI cannot be evaluated solely by numerical data; it must also consider how this reduction impacts the capabilities and well-being of developing countries. The **SDGs** framework offers a comprehensive yardstick to assess the broader impacts of CDR initiatives under the BRI. Carbon removal efforts should not only reduce emissions but also contribute positively to achieving SDGs, including restoring ecosystems damaged by climate change. As interviewee (A) highlighted, "This decade is the decade of ecosystem restoration because a lot of the ecosystem has suffered, and therefore, the effort has to be built on that through nature-based solutions."

In the context of the BRI, particularly the CPEC, there is limited evidence that China actively aligns BRI outcomes with the SDGs. If effectively measured, the impact of CDR initiatives on SDGs can enhance transparency, accountability, and reliability in assessing their true contribution to sustainable development. The capability framework for CDR introduces the concept of the "eyes of mankind" as a principle to evaluate the net global benefits and losses of a CDR initiative. This perspective requires assessing whether and how a CDR project benefits humanity as a whole, rather than merely serving the interests of a single country or region. However, significant challenges persist in the accounting processes of carbon removal, technology transfer, and climate finance (Craik & Burn, 2016). Existing assessments of BRI impacts are often produced by civil society organizations and independent think tanks rather than governmental or intergovernmental agencies from China or host countries.

Given the transnational nature of the BRI, evaluating CDR initiatives through the eyes of mankind remains a formidable task. Tools exist to measure the project's benefits to China or the host country, but capturing its global implications is far more challenging. A United Nations-sponsored mechanism could offer a feasible and practical approach to evaluating CDR projects under the BRI. Such an approach would ensure the inclusion of host countries, China, and developed nations in a shared accountability framework.

The Paris Agreement, a universally accepted framework for carbon reduction policies, serves as an ideal instrument to function as the "eyes of mankind" for evaluating CDR initiatives under the BRI. Any CDR policy must align with the principles and targets set forth in the Paris Agreement. As interviewee (A) emphasized, if CDR technologies can be "adaptable, accessible, and affordable," they hold

immense potential for achieving the goals outlined in the agreement. Some CDR techniques, including reforestation, afforestation (AR), and soil carbon sequestration, are already indirectly addressed under the mitigation portfolio in decisions made at the Conference of Parties (COP) (The NAS, 2018). Additionally, the bottom-up structure of the Paris Agreement empowers countries to include CDR strategies in their NDCs for emission reduction targets (Craik & Burn, 2016). Incorporating these governance mechanisms and evaluation tools into CDR initiatives under the BRI, particularly in Pakistan, can ensure a more transparent, equitable, and globally beneficial approach to addressing climate change while advancing national development goals.

Conclusion

This case study has two main objectives. The first is to test the idea of CDR as development in the context of the CPEC. The second is to assess the adequacy of the BRI to promote just CDR, using Sen as an evaluative framework. This case study analyzed the BRI's adequacy as an appropriate vehicle for CDR cooperation in the host countries. The answer seems equivocal. Some positive elements include mechanisms for technology transfer, capacity building, and financial support for the host countries. BRI cooperation also has many negative elements. In terms of process, it lacks transparency, is not bottom-up, and has little oversight. BRI is very self-interested and transactional. The case study makes a compelling case for reframing CDR as a form of development that requires us to look at different elements and emphasize different things.

This chapter analyses CDR under the capability framework and evaluates if carbon removal can be an act of well-being and advancing human capabilities. From the above discussion, the framing of CDR as development is possible, and it does make a difference as it can be one of the potential sources for increasing the engagement of developing countries in CDR scholarship and policymaking. The theory of capability of Amarta Sen provides a framework to conceptualize the idea of CDR for development. Sen's idea of justice also helps to structure policies for a just CDR. A just CDR is for the well-being of the people, and the process is open and democratic. Some CDR approaches have a higher chance of acceptance because of their higher co-benefits, like energy and food security. CDR in developing countries can focus more on co-benefits to meet specific development needs than solely as a climate response. Countries like Pakistan are concerned with addressing issues like poverty, food security, and water scarcity. CDR's use for addressing these issues adds value to CDR as a climate policy option when even mitigation is not a priority for countries like Pakistan. The emergence of CDR provides

another avenue to explore linkages between technology, environment, and the theory of capability. The role of technology and natural interventions under the CDR to secure and protect specific capabilities threatened due to climate change provides the capability approach to stretch its flexible framework for attaining valued capabilities. Meanwhile, amongst scholars from developing countries, there are concerns that specific techniques within CDR may cause more harm than benefit. The primary reason for this fear is the lack of complete understanding and research about CDR and the combined expression of CGE for SRM and CDR. The physical risks associated with CDR can hinder CDR's large-scale deployment and the use of these techniques in their climate response.

The objective of a just CDR initiative under the capability framework is to remove carbon and attain co-benefits like economic and energy security. The capability framework indicates that an open and informed discussion is essential for the democratic governance of CDR under the BRI. The governance stage suggests that as most countries are part of the BRI, it fulfills the capability framework's requirement of self-governance. At the same time, China, being the BRI's dominant and beneficial partner, owes a fiduciary responsibility for CDR initiatives. However, due to the lack of a neutral governance mechanism within the BRI, UNFCCC can act as the impartial spectator to determine, evaluate, and validate. The final stage of the framework is the outcome and active participation of host countries under the BRI enhances participatory and intergenerational justice. SDGs provide the informational base upon which the quantification of success or failure of CDR initiatives can be measured. However, the most crucial phase of the outcome is to evaluate Any CDR initiative, whether under the BRI or outside it, through the eyes of mankind, which is the Paris Agreement.

Moreover, cooperation amongst stakeholders is crucial whether CDR research occurs in a south-south or north-south dimension. Certain apprehensions in developing countries about CDR as a climate policy option exist. Developing countries do not want to hurt their climate justice movement and provide CDR as a tool for developed countries to evade their emission reduction responsibilities. The chances of carbon imperialism by the developed countries can be checked by enhancing the capacity building of developing countries and making the decision-making processes democratic. The interviewees stressed that cooperation is significant as climate change and environmental issues do not understand political boundaries, and climate change will impact developed and developing countries differently. CDR as a policy option will be more acceptable if it addresses climate change-related disasters like floods and droughts without limiting itself to only climate issues.

The study also investigates CDR's role in Pakistan's development under the BRI. The empirical research for this study suggests that there is currently no active CDR project or research program in Pakistan under the BRI. However, scholars and policymakers are open to CDR research if there is financial and technical assistance from international donors or countries like China. The findings also suggest that although there is a certain level of carbon storage infrastructure available in Pakistan, it is likely that Pakistan will prefer natural techniques of CDR. However, governance of CDR will be a gigantic task as it involves governance over a vast area of land and will require extensive consultation, cooperation, and understanding between federal, provincial, and local governments. In the case of Pakistan, natural and artificial CDR can have impacts in terms of change in land use, food security, and cultural impacts for the local community. Pakistan will need extensive external support for the research of CDR and for developing appropriate governance mechanisms. Given Pakistan's existing institutional and constitutional structure, it is hard for any government tier in Pakistan to move forward with CDR plans without national-level collaboration.

BRI supports development in the host countries but does not ensure low-carbon development. BRI is largely transactional and about expanding China's political influence, which is good for financial and technological support for implementing CDR initiatives. Still, BRI has limitations as a governance forum for CDR. BRI has no robust governance structures compared to the World Bank or IMF, which have very specific climate and human rights policies like IMF's performance standards or the World Bank's inspection Panel. China has made many announcements regarding environmental initiatives in the case of greening the BRI under the BRI. However, there are little or no concrete steps for MRV purposes in the host countries of the BRI.

The assessment of BRI regarding CDR suggests that some aspects of the BRI will not serve the host country well because BRI is a very top-down approach in which China can overrule the observations and concerns of the host countries. With limited agency for the host countries under the BRI, CDR cooperation under the BRI will have weaker governance than conventional multilateral development partnerships like the World Bank. The successful CDR-rooted development structures are likely to integrate the governance approach from the Paris Agreement, in which bottom-up governance is a more prominent element and allows the host country to structure research and governance according to their local circumstances. CDR is not an active climate policy in the host countries of the BRI, but scholars and policymakers from the global South are open to learning more about CDR. The empirical results show that CDR has multidimensional implications for social, economic, and political

governance structures at inter and intra-state levels. Developing countries have explored approaches like adaptation and mitigation, but resistance to CDR is likely more as it involves changing a society's social, economic, and governance structures. There is more acceptance for nature-based CDR techniques than technological approaches in a comparative sense.

Host countries of the BRI could consider adopting measures such as CDR alongside traditional mitigation strategies to manage the increased domestic emissions associated with BRI projects and advance their development goals. The BRI framework has the potential to support host countries through capacity building and financial assistance, both essential prerequisites for advancing CDR research and implementation. The structure and nature of BRI development suggest that future cooperation on CDR is not only possible but also strategically advantageous for both China and host countries.

Economic incentives tied to the BRI, combined with emission reduction responsibilities under the Paris Agreement, create an opportunity for China and partner nations to align the BRI with sustainable and low-carbon development objectives. However, the greening of the BRI has largely been a reactive measure in response to criticism directed at China for facilitating emission-intensive development in host countries. As such, active and well-defined partnerships on CDR or broader climate policy initiatives between China and host countries remain in nascent stages. Empirical evidence indicates no substantial partnership between China and Pakistan specifically on CDR at this stage. However, the BRI does provide foundational elements that could evolve into meaningful collaboration on CDR initiatives in the future. A significant limitation lies in the lack of democratic processes, informed consent mechanisms, and a focus on enhancing justice within the current BRI structure. Its governance and normative frameworks remain insufficient to address complex issues such as climate justice and advancing human capabilities.

The BRI's governance structure raises concerns about whether these partnerships can adequately prioritize protecting and enhancing human capabilities, especially given China's significant political and economic influence over host countries. As it stands, the BRI cannot provide a comprehensive governance framework for CDR initiatives. Transparency challenges and weak environmental standards further limit its effectiveness in this area. To address these gaps, the BRI will need to operate in alignment with global frameworks such as the Paris Agreement and other transnational platforms. The long-established research, governance, and financial mechanisms under the United Nations Framework Convention on Climate Change (UNFCCC) and related international institutions offer

pathways for China and the BRI to design and implement CDR initiatives that align with global regulatory and compliance standards. Collaborative efforts within these established frameworks can ensure that CDR initiatives are transparent, equitable, and contribute meaningfully to both global climate goals and local development priorities.

Chapter 4: Targeted Geoengineering: A Case Study of Glacier Protection in the Hindu-Kush Karakoram Himalayan (HKHK) Region

Introduction

Targeted geoengineering presents a significant opportunity to address the challenges associated with researching and governing global SRM, offering hope for mitigating the localized and regional impacts of climate change. This innovative approach not only provides a viable climate policy option but also holds the potential for generating meaningful developmental benefits. This case study explores the feasibility of protecting glaciers in the HKHK region through targeted geoengineering while examining its alignment with Amartya Sen's development concept. As a localized solution to climate change-related issues, targeted geoengineering offers the promise of a more sustainable future by addressing region-specific concerns. One of the core motivations of this project is to reframe CGE as a developmental tool capable of providing solutions to immediate and visible problems associated with climate change. This reframing aims to make CGE more relatable and actionable for communities in the global South by presenting technological solutions that address tangible, day-to-day challenges.

In many developing regions, CGE can be viewed as a tool for reducing global average temperatures but rather as a means of addressing critical local issues. For countries in the HKHK mountain region of South Asia, targeted geoengineering could serve as a key intervention to ensure balanced water flow from glaciers, mitigating catastrophic events such as Glacial Lake Outburst Floods (GLOF). This localized application underscores the importance of scale when considering the relevance and effectiveness of SRM technologies.

The scale of SRM application is a fundamental factor in evaluating its relevance, as environmental and climatic diversities significantly influence human capabilities. Different environmental scenarios create varying challenges and opportunities, highlighting the need for context-specific approaches to SRM. By aligning technological solutions with the lived realities of communities in vulnerable regions, targeted geoengineering can contribute not only to climate resilience but also to advancing developmental goals in a way that is both just and contextually appropriate.

Sustainable ice mass is vital in maintaining a healthy ecosystem, particularly in polar regions and mountain glaciers such as the Arctic and Himalayas, Hindu Kush, and Karakoram (HKHK). However, these glaciers are melting fast due to climate change (Mani,2021). Due to this situation, scientists are investigating options like radiative cooling to preserve ice, particularly for the sections exposed to direct sunlight (Li et al., 2022). This approach to ice preservation can be regarded as a form of targeted geoengineering, particularly when implemented at a regional level.

This chapter is a case study of targeted geoengineering focusing on the HKHK mountain region in HKHK is spread over 2,400 km in six countries: Afghanistan, Bhutan, China, India, Nepal, and Pakistan. The HKHK glacier preservation issue and its governance can allow us to experiment with smaller-scale forms of CGE and examine a form of CGE that can have greater relevance for the region's people and their development aspirations. There are discussions that the SRM approach can indirectly restrict the dangerous rise in sea levels by limiting the melting of glaciers and ice sheets in Greenland and the Arctic (NAP, 2021).

This analysis focuses specifically on the preservation of mountain glaciers, distinguishing them from coastal glaciers, which are often the subject of broader discussions on ice loss and sea level rise. Mountain glaciers, particularly in regions like the HKHK, play a critical role in sustaining water resources, agriculture, and livelihoods for millions of people. Unlike coastal glaciers, which are influenced by oceanic interactions, mountain glaciers are shaped primarily by atmospheric and topographical factors, making their preservation an entirely different challenge.

The potential use of CGE as a climate policy option to ensure the quality of life threatened due to an increase in global average temperature, especially in the context of HKHK, deserves scholarly and policy focus for several reasons. The case study seeks to investigate issues of scale surrounding where geoengineering as development is a local phenomenon. Targeted geoengineering offers a more direct approach to geoengineering at the local level. Targeted geoengineering may align more closely with Sen's view of development as a process of enhancing capabilities. This case study offers a chance to contrast targeted CGE with broader global CGE applications and examine the potential challenges of global SRM as a development solution.

HKHK has enormously contributed enormously to South Asia's energy, water, and food security through a continuous freshwater supply. The case of targeted geoengineering and HKHK becomes even more important because of the proximity of China and India and their quest to develop innovative climate response . China and India have started their research activities on CGE (Bala &

Gupta, 2019). In these circumstances, any large-scale CGE experiment from these two countries could have significant implications for neighboring South Asian countries. Given China's exposure to glacier protection, weather modification and targeted geoengineering can also be explored at the regional level.

The case study of South Asia is vital because this region has more than 2 billion people, and the rapid melting of glaciers in the HKHK region poses a threat to the capabilities of the people and development of the region. Moreover, including stakeholders from the global South in policy discussions concerning targeted geoengineering will enrich SRM (overall CGE) research and governance debates (Winickoff et al., 2015). South Asian countries are exposed to climate change impacts like floods, droughts, sea-level rise and melting of glaciers. Due to the dense population, regional geopolitics, and low resilience toward climate change, a regional-scale climate intervention can impact the vast population in South Asia. South Asia is a region where economic activity (vast agriculture and farming) heavily relies on stable and suitable environmental scenarios. Agriculture and allied industrial activities ensure food security for billions of people in the region. Agriculture in the region depends on a constant supply of fresh water that could be adversely affected due to climatic changes. South Asia's most threatened areas are the Himalayas and the mangrove area of Sundarbans (Hasnat et al., 2018). Forest in South Asia faces a severe threat because of deforestation and urbanization, and the air pollution indicator is one of the worst in the world (Hasnat et al., 2018). In addition to that, climate change threatens crucial ecosystems like glaciers and freshwater resources (Hasnat et al., 2018). Targeted geoengineering directed towards glacier preservation is important to be explored as a policy option to protect and maintain the capabilities associated with the environmental and resource attributes of the glaciers in the HKHK region. According to an estimate:

The glaciers in the HKHK mountain ranges are melting faster than the global average ice mass. HKHK glaciers are retreating at a rate of 0.3 meters per year in the west to 1.0 meters per year in the east. Field, satellite, and weather records confirm that 9 percent of the ice area in the early 1970s had disappeared by the early 2000s. Scenario studies—for example, Shea et al. (2015)—project that the glacier mass within the Everest region today will decrease 39–52 percent by 2050. The almost 55,000 glaciers in the HKHK mountains store more freshwater than any other region outside the North and South Poles. They contain estimated ice reserves of 163 cubic kilometers, of which almost 80 percent feed into three major rivers in South Asia:

the Indus, Ganges, and Brahmaputra. The basins of these three rivers are home to 750 million people (Mani, 2021, p.1).

Suppose a joint asset of South Asia like HKHK Glacier suffers from climatic changes (which it, of course, does). In that case, it will negatively impact the capabilities of poor South Asian people regardless of their national territories. Similarly, if a climate response policy like targeted geoengineering can help slow down the melting of glaciers or reduce their adverse impacts, then targeted geoengineering can be seen as an act to advance human capabilities threatened due to climate change. Forming groups to address climate-related challenges can help many individuals advance their capabilities, which they cannot do individually. 'The ability to form such groups is not only a source of improved capabilities but a capability itself' (Stewart, 2016, p. 20). The capability approach would treat HKHK glaciers as an asset for poor South Asian people to advance their capabilities related to fresh water, food security, and energy. It is an appropriate time for scholars and policymakers to start exploring cases like HKHK in their regions and explore the potential for the customization and regionalization of SRM instead of merely focusing on global SRM.

The viability of global SRM remains a subject of ongoing debate among scholars and policymakers, with targeted geoengineering emerging as a nuanced climate policy option. One perspective emphasizes the urgency of addressing the imminent risks of catastrophic climate disasters caused by anthropogenic climate change, arguing that geoengineering deserves serious consideration (NAP, 2021). On the other hand, a contrasting view advocates for discarding solar climate interventions entirely, highlighting their inherent risks and the potential to undermine global efforts focused on emissions reduction and mitigation (Biermann et al., 2022).

An emerging middle-ground perspective suggests that dismissing any climate intervention option, including large-scale CGE, would be premature. Climate change is a dynamic and evolving crisis, and responses must remain adaptable, keeping all viable options open (Bodansky & Hunt, 2020, p. 607). In this context, targeted geoengineering is seen not merely as a middle-ground compromise but rather as an alternative pathway. It offers the potential to exploit albedo modification at localized scales without significantly altering global radiative forcing levels, thereby addressing key governance concerns raised by Biermann et al., (2022).

This distinction is critical because while many forms of targeted geoengineering rely on albedo modification, their application remains highly constrained in scope and scale. These approaches would

still necessitate robust research and governance frameworks and agreements restricting albedo-based research would need to accommodate the specific needs of targeted applications. Furthermore, there is a possibility that targeted geoengineering, if successfully implemented, could pave the way for broader acceptance of SRM technologies on larger regional scales, such as the Arctic.

However, defining clear boundaries between acceptable and unacceptable scales of application remains a challenging task. The intricacies of these governance and operational concerns warrant closer examination. In the following section, I will explore the primary criticisms and opposition towards global SRM while making a case for why targeted geoengineering deserves heightened attention in contemporary climate policy discussions.

This chapter examines SRM as a development strategy with a specific focus on glacier preservation in the HKHK region. While the broader project investigates CGE within a developmental context, this chapter highlights SRM's potential to address pressing challenges like glacier melt. Glacier melt poses significant risks to development, well-being, and ecological balance (Mani, 2021; Al Jazeera, 2020). By narrowing the focus to regional and localized applications, this chapter aligns SRM's potential with Sen's principles of consent and agency, often at odds with global-scale SRM interventions. The case study explores SRM as a tool for glacier preservation and evaluates two primary questions: (1) Can SRM be conceptualized as a form of development at various scales, especially in ways that engage countries in the global South? (2) How might Sen's capability approach inform governance structures for effective and targeted SRM initiatives in the HKHK region?

The preservation of glaciers is critical due to the rapid melting of ice, threatening water security, livelihoods, and ecological stability. These risks necessitate a framework for governance that balances speculative and prescriptive approaches to inform future SRM strategies. While speculative, this evaluative framework underscores the need to explore governance and technological pathways for targeted SRM interventions at regional scales.

By applying Sen's capability approach, this chapter offers a grounded yet forward-looking perspective on SRM governance. Sen's framework, emphasizing consent, agency, and justice (Sen, 2009), is particularly relevant as it aligns with targeted interventions prioritizing vulnerable community's needs. In contrast to large-scale global SRM projects that risk undermining agency, smaller-scale interventions—such as regional albedo enhancement or aerosol injections—better adhere to these

principles (Bodansky & Hunt, 2020; Moore et al., 2020). The chapter positions itself as a forward-looking contribution to geoengineering discourse by transparently addressing uncertainties and emphasizing the flexibility of Sen's capability approach. It highlights that targeted SRM, focused on glacier preservation, offers an equitable and participatory pathway to address the immediate threats posed by glacier melt. This distinction bridges theoretical frameworks with real-world challenges, illustrating the capability approach's relevance in adaptation and disaster response contexts.

Furthermore, this analysis connects glacier preservation to broader discussions of climate adaptation. Unlike mitigation strategies aimed at reducing greenhouse gas emissions, adaptation and targeted SRM focus on managing current threats. Glacier melt exemplifies these immediate risks, jeopardizing water security and livelihoods while demanding urgent intervention. By contextualizing these risks through the capability approach, the chapter demonstrates how addressing vulnerability and fostering resilience can preserve human capabilities and promote sustainable development. Drawing on existing literature, the chapter emphasizes the capability approach's practical application in adaptation and disaster scenarios. This framework prioritizes reducing vulnerability, enhancing resilience, and ensuring equitable access to resources and decision-making. Linking these priorities to glacier preservation, the chapter underscores how regional SRM efforts can align with principles of agency and justice, offering meaningful solutions to one of climate change's most pressing consequences.

Ultimately, this chapter contributes to the ongoing dialogue on SRM governance by advocating for scalable, localized, and equitable approaches. It underscores the necessity of reconciling urgent environmental challenges with ethical governance, providing a roadmap for future research and policy initiatives in glacier preservation and beyond.

Application of the Capability Approach to Adaptation

Amartya Sen's capability approach presents a unique and transformative framework for understanding and addressing disaster management and climate adaptation (Lyster, 2018). It stands out with its focus on expanding individuals' capabilities and freedoms, enabling them to lead lives they value. This shift from a focus on purely material or economic considerations to one centered on human well-being and agency provides a powerful lens to tackle the vulnerabilities associated with

disasters and climate change. Within disaster management and climate adaptation, the capability approach highlights the importance of empowering individuals and communities to build resilience and adapt to evolving environmental conditions. Sen's framework is particularly beneficial in these contexts for several reasons.

The capability approach enables a focus on vulnerabilities and agency, distinguishing it from traditional disaster management frameworks that typically concentrate on response and recovery without addressing the underlying vulnerabilities that elevate the risk of harm. In contrast, the capability approach promotes reducing vulnerabilities and enhancing resilience by empowering individuals and communities (Sen, 2009). For instance, involving communities in planning and decision-making processes before an event enhances their agency and improves their capacity to respond effectively in times of crisis. One of the core characteristics of the capability approach is to focus on the community's ability to do what is beneficial for them (Robeyns, 2005). This concept parallels climate adaptation strategies, where ameliorating vulnerability is paramount. The decision-making process and its execution in disaster management and adaptation are as critical as the outcomes. According to the capability approach, these decision-making processes should be inclusive, democratic, and transparent (Sen, 2009). When affected communities are involved in planning and implementing disaster mitigation or adaptation strategies, the interventions become more tailored to local contexts and enhance the participants' agency. This participatory approach aligns with the normative principles of the capability approach, which emphasizes that development processes must respect individual freedoms and empower people to make life choices.

The capability approach offers a theoretical foundation that underscores the importance of equity and social justice in disaster events. The capability approach emphasizes the need to address inequalities, highlighting that marginalized groups such as low-income populations, women, and ethnic minorities—are often disproportionately affected by disasters (Nussbaum, 2009; Martinetti & Terzi, 2021). This approach necessitates that any adaptation or disaster management strategy prioritizes those most at risk, ensuring their protection while granting them the freedom to enhance their resilience and capabilities. For example, in flood-prone regions, targeted initiatives aimed at strengthening the resilience of vulnerable populations, such as constructing more durable homes, providing improved early warning systems, and establishing social safety nets, align with Sen's vision of development, underscoring the urgency and significance of our work.

The capability approach emphasizes the restoration of individual capabilities following a disaster. After such events, it is crucial not only to rebuild infrastructure and provide relief but also to focus on restoring individuals' capabilities. This involves ensuring access to essential services such as education, healthcare, social protection, and economic opportunities, which are vital for recovery and resilience against future challenges (Nussbaum, 2009). Viewing post-disaster recovery through the lens of capability is about mending the social fabric and empowering individuals to regain control over their lives.

An example of Amartya Sen's approach to disaster management can be observed more specifically in the context of climate justice in the adaptation and resilience approaches and the operationalization of the capability approach (Coggins et al., 2021; Cañizares-Gaztelu et al., 2024). In the real world, to combat flooding in Bangladesh, the policymakers concentrated on reducing vulnerabilities through initiatives and the implementation of community-driven early warning systems, as this approach ensures that individuals are not mere recipients of aid but active participants in enhancing their resilience (Choudhury & Haque, 2024). These strategies shield people from the immediate effects of floods while bolstering their capacity to recover and lead meaningful lives in the aftermath of a disaster. Sen's capability approach provides a valuable theoretical and practical framework for disaster management and climate adaptation by emphasizing empowerment, equity, and inclusive processes. This allows policymakers to design reactive and proactive interventions in addressing the vulnerabilities faced by those most at risk from disasters and climate change.

Global SRM and the Capabilities Approach

Framing SRM through the lens of development underscores critical challenges, particularly when evaluated using Amartya Sen's capability approach. Global SRM, often proposed as a tool to mitigate climate change, faces criticism for undermining consent, equity, and justice principles. Scholars like Frank Biermann (2022) highlight the uneven power dynamics, lack of inclusivity, and potential negative consequences of global SRM initiatives. These concerns align with Sen's emphasis on agency, underscoring the need for governance structures that ensure vulnerable stakeholders have a meaningful voice in decision-making. Moreover, global SRM risks exacerbating existing inequalities by prioritizing developed nations' interests while neglecting or harming the global South (Biermann & Möller, 2019).

The security implications of global SRM further illustrates its limitations. Glacier melting, a localized climate challenge, exemplifies how environmental threats can escalate into broader security crises. For instance, dwindling water resources caused by glacier melt could intensify tensions and provoke conflicts among neighboring countries, particularly in regions already facing resource scarcity (Milner et al., 2017).

In contrast, targeted SRM approaches, such as those focused on glacier preservation, offer a more direct and regionally relevant method for addressing these challenges. Buck's research (2022) provides a framework for understanding how SRM can foster "negative peace" by mitigating some conflict drivers. Targeted SRM aligns more closely with the development priorities of the global South by emphasizing regional well-being, inclusivity, and equitable outcomes. Unlike global SRM, which often functions as a top-down solution favoring the developed world, targeted SRM promotes cooperation and localized development (Moore et al., 2020).

This chapter highlights the potential of targeted SRM, guided by Sen's capability approach, as a concrete and equitable intervention for addressing urgent regional issues like glacier melt. By prioritizing agency and justice, targeted SRM offers a viable alternative to global initiatives, demonstrating how development-focused strategies can attract greater support and participation from the global South. This distinction underscores the broader developmental implications of SRM and the importance of localized, context-specific approaches to global climate challenges.

Opposition Towards Global SRM

There are several grounds due to which practical application of global SRM appears difficult and the option of targeted geoengineering is viable. First, some scholars have advocated non-use agreements for global SRM and asked national governments worldwide to refrain from funding SRM projects, endorsing their deployment, or seeking support from international institutions (Biermann et al., 2022). The proponents of non-use agreements have argued that given the contentious nature of SRM, it would be better if governments worldwide came up with an international non-use agreement on solar geoengineering. More than 60 scholars launched a global initiative calling for an international non-use agreement on solar geoengineering. The international non-use agreement on solar geoengineering has received a mixed response from scholars and policymakers (Parson et al., 2024). This option has been presented as a governance option and is based on five principles:

- (i) No public funding

- (ii) No outdoor experiment
- (iii) No patents
- (iv) No deployment
- (v) No support in international institutions

Informants in our interviews expressed support for academic and research activities regarding global SRM, but on the deployment side, they voiced significant reservations. Interviewee (P) stated, “So it is good to do the academic research properly, at least for a couple of years, maybe a few more years.” An interviewee (O) explained that some provisions of the non-use agreement make things more complex:

If you call your research project solar geoengineering, you would be stopped (but) if you call it in a different manner, you would be allowed. So that is a very tricky situation. And the public funding, we need responsible, publicly funded research program in democratic countries. And, of course, deployment is something totally different. We do not know much about it. I think if you want to deploy technology like this, you have to be really clear and ensure about the benefits and the risks of this technology.

The interviewees were cautious about furthering SRM research, deployment, and funding without appropriate governance. However, there was limited support for the idea of altogether abandoning or discarding the idea of research on SRM, as proposed by the proponents of the non-use agreement. The respondents acknowledge that given the urgency of climate change issues in developing countries and the peculiar challenges faced by South Asia, every option concerning climate change management (including SRM) should be available to South Asian policymakers. In this scenario, limiting funding for research (not deployment) may hurt the process of knowledge creation, especially for developing countries to make an informed decision about SRM. Knowledge about SRM is nascent, and halting the research processes with public funding can limit human understanding when it needs more knowledge to consider SRM as a policy option for climate change (Rahman et al., 2018; Parson et al., 2024). The capability approach endorses getting additional knowledge to advance capabilities that lead to enhanced choices.

The second challenge for deploying global SRM is related to its security implications that strengthen the argument that deployment of global SRM may be a difficult option to pursue especially in South Asia. SRM has an attraction for military and security organizations. For example, some SRM

techniques, like solar shields, could be used for military applications (Keith, 2000; Patnaik et al., 2022). On the other hand, developing countries are already sensitive about this security capability of CGE as cloud seeding technology was used during the Vietnam war by the USA (Novak, 2015). A few years ago, Iranian President Ahmadinejad also blamed European countries for deliberately modifying rainfall patterns in Iran and causing a water deficiency in Lake Urmia (Dalby & Moussavi, 2016). This security aspect of SRM can have severe geopolitical implications at the global and regional levels. The concept of counter-geoengineering is also a related idea that aims to check undesirable geoengineering activities of another country (Parker et al., 2018). Another security aspect of CGE is that terrorists can try to obtain and deploy this technology. The rogue elements can try to capture certain CGE technologies, and due to weak governance, some developing countries are more vulnerable in this regard (Chalecki & Ferrari, 2018). In addition, private CGE is possible, as wealthy persons could pursue these technologies independently (Bodansky, 2012, p.12). This scenario may result in more rules and regulations at the international level to avoid the harmful use of CGE, and in some cases, may lead to a military action just like terrorism (Bodansky, 2012). Any major unilateral experiment or deployment of CDR or SRM can lead to a global crisis and create a predicament regarding acceptability (Blackstock & Long, 2010).

Researching CGE, especially global SRM, may be difficult, given that environmental issues have long been analyzed from a security perspective. The geophysical effects like change in GHG have become part of geopolitical debates (Dalby, 2015). Due to various reasons like time, scale, and intensity, CGE will carry the potential for conflict among states (Boyd, 2009; Dalby, 2015; Morton, 2017; Parker et al., 2018). It is a well-known fact that South Asia is the center of some of the most intense geopolitical developments in the world, primarily because of the US-China rivalry, India-China tensions, and Pakistan-India history of wars. It is unlikely that sensitive technology like SRM will remain insulated from the geopolitical dimensions of the region. The "CE could lead to major advances in knowledge relevant for developing weather as a military tool" (Olson, 2011, ix). The securitization of SRM is even more crucial in Asia because China, India, and Pakistan are the three nuclear-armed neighboring states. If all three neighbors or any one of them develops their capabilities for large-scale SRM for offensive purposes, there could be severe implications for regional peace and stability. Unilateral action regarding SRM can trigger a reaction from other states. In this situation, the active role of global powers like China and the USA is essential in designing governance mechanisms regarding SRM research (Barrett, 2014). Such matters increasingly suggest the need to consider the planet as a limited

entity, one in which geopolitical ambition must be bounded by at least some restraints to prevent nuclear and other catastrophes (Deudney, 2007). According to Dalby:

The discussion of geoengineering proceeds apace as the limited success of climate mitigation focuses attention on what comes next. Thinking about how to govern geoengineering before major experiments are tried unilaterally might be the key to preventing future conflicts over such practical issues as what temperature the planet ought to be. Such questions are the key to the new geopolitics of the Anthropocene, a debate to which geography in general and political geography in particular could have much to contribute (Dalby, 2015).

India, China, and Pakistan are three nuclear-armed states, and their experience in managing nuclear technology could have lessons for these countries to govern CGE research. Nuclear weapons have played a notable role in shaping the geopolitics of Asia. Asia has the largest concentration of nuclear weapons globally (Pekkanen et al., 2014). There might be some lessons to be learned from the governance of the nuclear regime and the application of those lessons to the climate-geoengineering regime (Chalecki, 2021; Heal, 2010). These three nuclear-armed countries' sophisticated military capabilities may help them design their CGE programs under conventional command and control systems. The dominant role of military organizations in Asian countries regarding CGE research can enhance the security aspect of geoengineering techniques.

Our study participants also discussed a connection between CGE, geopolitics, and the militarization of SRM. The consideration of CGE as a potential offensive weapon is not limited to South Asia but is a concern shared by experts worldwide (Interviewee-M). The need for knowledge, which can put a country at a disadvantageous position against a country with better knowledge and research about CGE. An interviewee (M) stated:

And, in this, the geopolitical aspects of, or the debates where solar, radiation management, without the preparation appropriate information if countries like when they say yes, then there are the risks of being again deprived or disproportionately impacted by these initiatives. If we go and implement these things without any information. So voice of countries like Bangladesh is very important in sort of coming up at this session to either do more research before implementing these things at a global scale.

An interviewee(M) stated: "I can see there is a real concern here, in my opinion, and that is not just the South Asia, but globally, there has been a concern around using geoengineering technologies as a

weapon for security issues.” Most of the respondents argued for extreme care and caution in pursuing CGE research. An interviewee (N) said, “theoretically, at least, it is possible to imagine countries trying to harm other countries by doing geoengineering, (but) of course, it would not be undetectable.” There is concern that sensitive technologies like CGE may aggravate the tension in the region. An interviewee (N) stated, “I think, from the geopolitical point of view, it has always been a very difficult region to get any cooperation.” Given the fact that India, China, and Pakistan are highly militarized states with nuclear capabilities and a history of wars and regional disputes, this region may become a testing ground for the geopolitical dimension of CGE because of the climatic vulnerability of the region and the desire to have supremacy over HKHK glaciers to shape the water security of the region. Due to the potential militarization of CGE technologies and exacerbating the regional conflict, the respondents believe there should be an oversight forum to check the security dimension of CGE approaches. An interviewee (O) stated that the “United Nations Security Council has to be there because of the geopolitical implication of solar geoengineering or SRM.” These security and governance concerns related to global SRM support the argument that it is time to focus, understand, and research targeted geoengineering.

In addition to these concerns towards global SRM, an analysis from the capability perspective would also look at the scale of delivery and agency concerning any intervention to manage climate change-related issues. The scale of SRM and the agency of the participant countries are interconnected. A global SRM may remove agency from the global South, especially if the global SRM’s governance is placed in the hands of technologically advanced states or an international organization. The economic benefits of global SRM can become the exclusive domain of the developed countries due to their hegemonic position of global economic governance; the global South will again be in a disadvantageous position.

Economic facts are certainly significant for SG (Solar-Geoengineering). However, the economics of SG, by and large, do not seem to clash with the soft constraints posed by current economic systems and therefore this technology has a certain degree of feasibility with regard to this ambit. Only the international economic dynamics triggered by SG could be significant for its feasibility, albeit not necessarily in a negative way, as long as first-movers can reap part of the benefit and, through their power and authoritativeness, are willing to induce other countries to collaborate (Grasso, 2019, p. 220).

For many countries, the economic cost of managing climate change has remained essential to their decision to support a particular policy option. This way, SRM can contribute through temperature reduction to increase welfare, thereby counterbalancing the welfare losses associated with climate change (Grasso, 2019, p.220). SRM may create a competitive environment among countries where some may pursue SRM because it will give them an edge over their rival countries (Grasso, 2019). Countries with strong economies and technical capabilities will likely be rewarded in this race (Grasso, 2019). SRM could be used as a stopgap, giving society additional time to cut emissions and develop effective carbon removal techniques to accommodate future generations' problems (McKinnon, 2018). This scenario places developed countries in an advantageous position regarding deploying global SRM.

Moreover, global SRM can reduce the option of “specific consent” from developing countries. The capability approach argues for considering the peculiar circumstances of individuals and communities while evaluating their development aspect. The case of geoengineering is no different, as people directly impacted by climate change are likely to have different opinions about the need for targeted geoengineering than those who are mere observers of the impacts of climate change. Many cultural peculiarities will also be relevant in SRM research for framing policies and establishing institutions (Bala & Gupta, 2019; Sugiyama et al., 2017). The moral aspect of CGE is crucial as innovation and new technologies must interact with society's social and cultural values. SRM has low feasibility if we testify about it with a moral compass because of various social and legal constraints involved in its research and deployment (Grasso, 2019, p. 222). If countries design geoengineering research and governance that addresses moral concerns, geoengineering will gain more legitimacy and acceptance in those countries (Grasso, 2019, p. 222). The moral and social values concerning geoengineering are relative and differ from one society to another. For example, a study found that:

More pessimistic experts about climate change are less receptive to geoengineering than less pessimistic experts. However, experts in a country with the extreme threat of climate change are more receptive than experts whose country have less threat from climate change. Thus, when respondents are more personally affected, their views are closer to what rational cost-benefit analyses predict (Dannenberg & Zitzelsberger, 2019).

The relative acceptance of SRM has two dimensions: the global north-south aspect and group beliefs within society. An interviewee (O) noted regarding the north-south dimension that the public views

about CGE differ. While referring to a study on the acceptance of SRM as a climate policy approach (Interviewee-O) stated that “developing countries were, generally, more concerned about climate change (and) also, they were more supportive (than developed countries) of doing SRM as a potential option to address climate change.” The global South and global North have significantly different views about approaching the issue of climate change and looking at various climate policy options, including CGE. Moreover, within a society, various groups and segments can have divergent views about applying CGE as a climate policy option. These groups and civil society representatives can influence the policy-making processes and allocation of budgets for research of CGE in developing countries. For example, an interviewee (M) stated:

That is probably in from a religious point of view; you probably be in conflict with God's work. So some of those concerns will also be raised in addition to sort of the scientific challenges or the concerns that people raise with monsoons and other things.

The concerns associated with CGE can be exacerbated in countries and communities that need an in-depth understanding of CGE. If the public does not adequately understand the role and purpose of CGE research, it could receive an adverse reaction from the public (Interviewee-M). There are fears in the general public about large-scale SRM, and they take it (SRM) as an intervention through which scientists will try to hide the sun and manipulate it (Interviewee-M). The interviewees were optimistic that the general public's views could be influenced regarding more research and structure of SRM governance with proper dissemination of knowledge and awareness activities. A critical reason there could be a concern in developing countries regarding CGE research is that climate models suggest that the application of SRM will have different impacts on different regions. As an interviewee (N) stated:

I do take the argument seriously. I think I have done simulations in China that clearly show that in particular regions, if you did (SRM), some things would be much worse affected than other regions. And, it certainly, on the computer anyway, it is possible to make modifications that would have these regional disparities.

The difference in societal norms and relative implications of SRM deployment can influence the future of CGE research in developing countries. Due to extreme vulnerability from climate change and a lack of the financial and technological capacity to manage it, South Asia will find it difficult to integrate emerging approaches like global SRM into their existing climate policy responses.

The climate justice moment is another ground that poses a challenge to the practical application of global SRM. Developing countries' colonial experience and subsequent apprehensions about neoliberal dominance in GEG have strengthened the climate justice movement (Sultana, 2022). The developed countries have used neoliberal ideologies so that their governance model appears natural and an inherent component of GEG (Okereke, 2010). The idea of economic exploitation suggests that developed countries have introduced and promoted market-based solutions to the issue of climate change, which are beneficial to developed countries. The emergence of a market-based solution in environmental governance reaffirms the continuation of neoliberal economic order (Bulkeley et al., 2014; Bailey et al., 2011; Bernstein, 2001). The emergence of CGE technologies also has a market and commercial aspect, as some of the characteristics of SRM support nonstate governance models (Reynolds, 2019). SRM has found support from capitalists and fossil fuel sections of the global economy (Gunderson et al., 2018). This support of SRM from neoliberals can be worrisome for the governments of developing countries. Neoliberal environmentalism has significantly reduced the state's authority and presented the private sector and non-governmental organizations (NGOs) as a suitable alternative to the state-owned apparatus (Bulkeley et al., 2014). Because of the hegemony of neoliberal environmentalism, environmental governance has focused more on growth and development (of developed countries) rather than on social justice and fairness (Bailey et al., 2011; Okereke, 2010). Likely, global SRM's research and governance debates in the global South will also be analyzed through the climate justice aspect.

IPCC has noted that some CGE techniques may have a role in limiting the global average temperature increase by 1.5 C in the future. An interviewee (N) described the future of SRM in developing countries as being "very likely to be done at some point." The informants revealed during the interviews that the SRM is a relevant subject, and as a matter of research, it will become more and more part of academic and policy debates. Initiatives like SRMGI and C2G2 have promoted CGE research and provided knowledge to scholars and policymakers in South Asia. Their future engagement in South Asia will be crucial for shaping the research programs there.

The Idea of Targeted Geoengineering

Implementing targeted SRM for glacier preservation offers a promising approach to addressing localized and regional climate impacts. Research on Arctic ice preservation has demonstrated the potential of techniques such as albedo enhancement and reflective covers in slowing ice melt and stabilizing critical ice masses. While these methods were primarily designed for vast polar

environments, they provide valuable insights for adapting SRM interventions to high-altitude glacial systems, such as those in the HKHK region. However, these adaptations must consider the unique vulnerabilities and environmental characteristics of mountainous glaciers.

Mountainous glaciers face challenges that are distinct from those encountered in polar regions, necessitating carefully tailored management strategies. In polar areas, interventions like sea curtains are employed to mitigate oceanic impacts on ice stability. In contrast, mountainous glaciers are primarily shaped by atmospheric conditions, topography, and seasonal weather variability. The HKHK region, often referred to as the "Third Pole," is an ecological and hydrological lifeline, sustaining water resources for millions of people across South and Central Asia (Mani, 2021). Accelerated glacier melt in this region threatens ecosystems, water security, agriculture, and livelihoods, highlighting the urgent need for innovative and effective preservation strategies.

Unlike large-scale global SRM interventions, targeted geoengineering focuses on protecting and preserving specific areas of critical environmental importance through limited and localized actions. This approach is designed to reduce risks associated with global SRM while delivering measurable benefits to vulnerable ecosystems. The ongoing debate around targeted geoengineering underscores its potential role in preserving vital ecosystems, such as slowing glacier melt in high-altitude regions or stabilizing Arctic ice sheets (Bodansky & Hunt, 2020, p. 597). Adapting SRM strategies to mountainous environments like the HKHK region requires a nuanced understanding of regional climatic and ecological dynamics. By drawing on lessons from Arctic SRM interventions and tailoring them to the distinct characteristics of mountainous glaciers, targeted geoengineering has the potential to serve as a viable and effective tool for preserving these critical ecosystems in the face of accelerating climate change. The deployment of:

Targeted geoengineering is done on regional scales but aims to conserve the various parts of the global climate and earth system. Hence, as with solar geoengineering, it is a proactive measure. Many international treaties aim to preserve the status quo, prohibit certain activities, and encourage conservation (Moore et al., 2020,p.109).

The scale and approach behind targeted climate interventions are to protect and preserve the environment. There may be a difference of opinion about the deployment of SRM, particularly SAI; however, approaches to protecting glaciers from melting are like adaptation in many ways (Bodansky & Hunt, 2020). The approaches, which include protecting the Arctic, spreading the reflecting beads

over glaciers, and thickening the ice of glaciers, do not involve disturbing the global ecosystem. However, they are, in a way, preservation and adaptation (Bodnasky & Hunt, 2020, p. 608). The criteria for judging the targeted interventions, even if they involve certain CGE-related technologies, should be that which is used for adaptation and mitigation because they both don't disrupt the global ecosystem. Unlike controversial approaches like SAI (Bodansky & Hunt, 2020, p. 596), most of the governance of SRM has focused on the global level (Hubert, 2018), which may not be adequate for regional-level interventions (Hester, 2013). "Doing solar geoengineering would ideally need at least near-global consensus, while targeted approaches require only a subset of states to agree on them." (Moore et al., 2020, p.109). One potential benefit of targeted geoengineering is that, unlike global geoengineering, which carries global risk, local geoengineering will have limited and local impacts (positive or negative) (Wolovick & Moore, 2018). Targeted interventions provide an opportunity to govern engineering approaches at a regional level (Bodansky & Hunt, 2020). The limited scope of targeted geoengineering appeals to scholars and policymakers who have apprehensions about the global implications of SRM.

In a way, targeted geoengineering can address specific concerns of scholars and policymakers associated with global-scale interventions. Targeted intervention normalizes the engineering aspect of managing climate change, like adaptation and mitigation, instead of creating unknown fears in human minds (Bodansky & Hunt, 2002). Unlike global geoengineering, limited climate interventions have potentially fewer moral concerns because there will be fewer chances of termination shock (Moore et al., 2020). After all, limited approaches protect the environment and do not offset the emission reduction responsibilities (Bodnasky & Hunt, 2020; Moore et al., 2020). These approaches will be deployed locally, making it easier for governments to obtain local communities' feedback and structure their approaches accordingly (Moore et al., 2020). One example of targeted intervention is preserving and protecting the Arctic through various engineering techniques. The Arctic is considered one of the critical components of the global climate system, and with the rate at which ice is melting in the Arctic, there are chances that summer Arctic Sea ice will go. There may be a significant increase in sea level.

The idea of targeted geoengineering is gaining traction among researchers, especially in the case of Arctic intervention. The Arctic is one of the tipping points with enormous importance and implications for regional and global climate systems. A few scholars focus on "tipping points" to protect and preserve the global climate system (Lenton et al., 2019). These tipping points include the Greenland

Ice Sheet, the Amazon rainforest, and the Antarctic Ice Sheet. There are indications that a discharge from the West Antarctic Ice Sheet (WAIS) has started that can cause significant damage to the ice sheet, lead to significant sea-level rise, and threaten some global cities like New York and Tokyo (Feldmann et al., 2019). The Arctic is warming faster, causing sea ice loss and the Greenland ice sheet (CCAG, 2021). The loss of arctic ice contributes to global sea-level rise and global warming (CCAG, 2021). The protection of the ice sheet appears more viable than allowing the ice sheet to collapse and cause damage to human lives and livelihoods (Moore et al., 2020). Traditional approaches like adaptation and mitigation may not be enough to control the damage due to their indirect and slow impact on the melting of the Arctic (Bodansky & Hunt, 2020, p. 596). This situation demands that scientists and policymakers deliberate about direct, fast interventions that can slow down the processes of anthropogenic climate change.

Several proposals are under consideration to manage or restrict the rapid melting of the Arctic or slow it down. First, an idea has been floated by ICE911, now known as arctic-ICE, a not-for-profit organization, to disperse silicate beads over polar sea ice to increase its reflectivity and start a cooling situation in the Arctic (Niiler, 2019). This is a form of SRM as it relies on altering albedo at small scales. Another possible way to stabilize the Arctic sheet may be “mass deposition in coastal regions around Pine Island and Thwaites glaciers” (Feldmann et al., 2019). Some other approaches that have been conceptualized for targeted intervention in the Arctic are:

(1) preservation of floating ice shelves by building walls or positioning curtains to block off access to salty, warm deep currents; (2) building extra buttressing points that ice shelves can ground on and stabilize the inland ice; (3) slowing the outlet glaciers on land where they slide rapidly over sediments by drying the sediments, removing the lubrication at their beds and slowing the glaciers”(Moore et al., 2020, p.111).

The case of the Arctic intervention explains how targeted interventions differ from global interventions. This approach is more about protecting and preserving ice sheets than changing the environment altogether. Amongst all the ideas discussed, the idea that “ice sheet conservation appears the most promising of the interventions we present” (Moore et al., 2020,p.112). The Arctic intervention will only address a specific aspect of the environment and climate change; thus, it does not pose a risk of moral hazard as it does not appear as an alternative to emission reduction (Bodansky & Hunt, 2020, pp. 597-598). Scholars' emphasis on treating targeted interventions like adaptation or mitigation allows developing countries to better explore targeted interventions than global SRM.

Preserving Arctic ice has become a critical focus due to its direct link to sea level rise. Scientists are exploring a range of geotechnical strategies to mitigate ice melt, including altering surface albedo, reinforcing shear margins, thickening ice shelves to improve stability, and preventing warm seawater intrusion snowfall (Lockley et al., 2020). Additional approaches, such as draining or freezing the underlying bed, constructing barriers to retain snow, and strengthening fractured shelves, aim to slow disintegration. Regional climate engineering and local cloud seeding are also being studied to cool glaciers and increase snowfall (Lockley et al., 2020). These interventions target the rapid melting of polar ice masses to reduce sea level rise and its impacts on coastal regions.

The governance of any form of CGE is a critical topic, particularly when considering interventions in ecologically sensitive regions such as the Arctic. In the case of Arctic intervention, the Arctic Council serves as a potential platform for research, dialogue, and deliberation on targeted geoengineering strategies (Bodansky & Hunt, 2020, pp. 597–598). From the perspective of international law, Arctic intervention does not significantly deviate from established norms. Actions aimed at mitigating the impacts of climate change in the Arctic align with the principles of international environmental law. Additionally, international human rights law norms, particularly those concerning the participation of local and indigenous communities in decision-making processes, would also apply to Arctic geoengineering initiatives (Bodansky & Hunt, 2020, p. 613). Should research reveal significant harm resulting from Arctic interventions, an environmental impact assessment (EIA) would become essential to ensure accountability and transparency.

Parallel research efforts are also underway in other regions. For example, Australian scientists are exploring marine cloud brightening as a geoengineering approach to protect the Great Barrier Reef from the impacts of warming seas (Tollefson, 2021). This highlights a broader trend of regional and targeted geoengineering strategies tailored to address specific climate challenges. Other regions, such as the HKHK mountain ranges, play a significant role in global water systems through glacial melt (CCAG, 2021). The rapid melting of glaciers in the HKHK region threatens water security, agriculture, and livelihoods across South Asia, where millions depend on sustainable freshwater flows originating from these glaciers.

Despite the urgency of addressing these challenges, discussions around SRM and targeted geoengineering have predominantly focused on the climate issues of developed countries. Consequently, there remains limited academic and policy literature exploring how developing countries perceive and integrate SRM and targeted geoengineering into their national climate change

strategies. The heterogeneity of SRM effects—where outcomes may vary significantly by region—creates incentives for countries to form small-scale coalitions to address their localized climate priorities (Ricke et al., 2013). For South Asian nations, targeted geoengineering could emerge as a viable strategy for protecting HKHK glaciers from the combined impacts of rising global temperatures and black carbon deposition.

The urgency of glacier preservation has also gained recognition at the international level. The United Nations has designated 2025 as the Year of Glacier Preservation, with plans for an international conference on glacier protection under the framework of the SDGs (UN, 2024). This recognition underscores the connection between glacier protection and the advancement of SDG targets, particularly those related to climate action, water security, and sustainable ecosystems. However, preserving HKHK glaciers presents unique challenges distinct from Arctic preservation, both in terms of methods and governance frameworks. The HKHK region's complex topography, regional geopolitics, and socio-economic dependencies require bespoke strategies tailored to local contexts. While Arctic preservation relies heavily on albedo enhancement and ice shelf stabilization, interventions in the HKHK region may require more integrated approaches, combining localized SRM techniques with nature-based solutions and regional policy cooperation. In conclusion, advancing targeted geoengineering in regions like the HKHK requires region-specific governance frameworks, community participation, and alignment with global standards such as the Paris Agreement and SDG agenda. These interventions must remain transparent, equitable, and attuned to the needs and capabilities of local communities to ensure long-term resilience and sustainability.

Targeted Geoengineering for Development

It is possible to explore global SRM simultaneously and targeted geoengineering for development. However, targeted geoengineering has more tractable features as it is directed to more immediate threats to unfreedoms like loss of water sources, floods, and disaster prevention. Sen's idea of development is critical for understanding targeted geoengineering as an approach for development in the HKHK region. Looking at targeted geoengineering's impact on people's lives is essential instead of merely considering it as a climate policy option. What capabilities can humans lose if HKHK glaciers melt, and how does target geoengineering help protect those capabilities threatened due to climate change? First, the capability approach can help us better understand the impact and role of climate policies on human capabilities:

Another aspect of development under the capability approach is looking at environmental degradation as a capability reduction. In the case of people already living under the poverty line, environmental degradation is more harmful than people living in a relatively better environment. South Asia is a developing region where a significant population lives below the poverty line, and any further deterioration in the environment (like the melting of glaciers) will place the poor population in a disadvantageous position. The capability approach helps us understand how environmental conditions impact the capabilities of poor people.

Environmental diversities: variations in environmental conditions, such as climatic circumstances (temperature ranges, rainfall, flooding and so on), can influence what a person gets out of a given level of income. Heating and clothing requirements of the poor in colder climates cause problems that may not be shared by equally poor people in warmer lands. The presence of infectious diseases in a region (from malaria and cholera to AIDS) alters the quality of life that inhabitants of that region may enjoy. So do pollution and other environmental handicaps (Sen, 1999, p.70).

The research and knowledge enhancement about targeted geoengineering for developing countries to negotiate better for their interests is also a development. In this world where people have common interests despite diverse backgrounds, it is difficult to exclude people of a single country from decision-making and knowledge-acquiring processes (Sen, 2009, p.403). The knowledge-enhancing capability can reduce injustice and structure social opportunities to lead to human well-being collectively. While appreciating the example of economies that have invested early in human knowledge and capacities, Sen has argued that "they have reaped as they have sown" (Sen, 1999, p.41). The capability framework supports funding for research, enabling policymakers to make informed decisions about targeted geoengineering use as a climate policy option. Regarding deployment, the capability approach supports a participatory approach in which concerned stakeholders should be part of the decision-making processes. The capability framework can help us examine certain technologies from a different perspective for human development. The framework below presents the application of the capability approach for attaining a just-targeted geoengineering phase in the HKHK region.

Another aspect of targeted geoengineering as a development is access to advanced technology. Technology's role is crucial in getting expertise in CGE research. For example, computer-based climate models are critical instruments shaping the future of targeted interventions or geoengineering in climate governance. Through computer models, scientists can assess the viability of SRM (and

targeted geoengineering) at the theoretical level and create scenarios about the application and range of SRM for political decisions (Grasso, 2019). These strategic projects help gather data from small-scale experiments for managing climate change (Grasso, 2019, p. 220).

Targeted geoengineering as part of climate policy response may be significant in regional ecosystems. Targeted geoengineering as development can help protect tipping points and contribute to the development of a particular region. It is necessary to understand that some communities are already vulnerable and suffering due to climate change, and the rapid melting of glaciers will adversely impact them. This situation applies especially to South Asia, where HKHK glaciers are vital in people's daily lives. There is a possibility that:

Climate engineering technologies on this (targeted or regional) scale potentially could seek to protect especially vulnerable polar regions or preserve precipitation cycles that supply critical water supplies over subcontinental or regional areas (Hester, 2013, p.168).

In the case of the HKHK region, targeted geoengineering can be explored for protecting and preserving HKHK glaciers and contributing to the economic activity in the region. Now, climate change is also an issue of production and not just a traditional environmental problem (Dalby, 2015). Targeted geoengineering has also been evaluated from the monetary aspect, such as preserving ice sheets and subsequent implications for the local economy (Moore et al., 2020). Similarly, the preservation of HKHK glaciers through targeted geoengineering and its economic impact on South Asian countries can be explored.

Why Resort to Glacier Preservation in the HKHK Region?

Glacier preservation through targeted geoengineering represents a promising avenue for addressing the developmental risks posed by glacier melt. It bridges environmental and developmental goals, offering both immediate relief and a pathway towards long-term sustainability, while aligning with the principles of justice, equity, and capability enhancement. Glacier melt poses significant developmental risks, threatening water security, agriculture, and the livelihoods of millions (Shahgedanova, 2021). Glaciers, particularly in high-altitude regions like the HKHK, are retreating rapidly due to climate change, disrupting essential water supplies and jeopardizing agriculture, hydropower, and biodiversity (Mani, 2021). These impacts extend beyond local communities to regional and global levels, compounding social and economic vulnerabilities. The capability approach

highlights the severe deprivations caused by glacier melt, such as diminished access to water and loss of livelihoods, underscoring the need for equitable and innovative solutions.

Efforts to preserve glaciers encompass both localized and regional-scale interventions. Local methods, such as snow fences, reflective covers, and microspheres, focus on enhancing surface albedo to reduce ice melt. While relatively straightforward and requiring minimal coordination, these approaches are limited in scale and may not adequately address the challenges of large glacial systems under severe climatic stress (Prabu, 2022).

Regional strategies, including SRM and MCB, take a broader approach by modifying atmospheric properties to reduce solar radiation and promote cooling (Crutzen, 2006). SRM involves dispersing aerosols into the stratosphere to reflect sunlight, while MCB brightens clouds to achieve similar effects. These methods hold significant potential for glacier preservation in regions like the HKHK but require further research to address uncertainties regarding efficacy, environmental side effects, and governance.

While regional SRM technologies such as SAI and MCB remain speculative, their development is crucial given the urgency of glacier preservation. Substantial investments in research, coupled with anticipatory assessments of risks and governance challenges, are necessary to prepare for potential deployment. Proactively addressing these challenges ensures that glacier preservation aligns with principles of equity, sustainability, and regional cooperation.

The HKHK region provides an important opportunity to examine glacier engineering research, but there is minimal research on the subject. The downstream effects of melting glaciers deserve attention because of the severe economic, social, and political implications (Milner et al., 2017). At the end of the century, there are chances that we will significantly lose glaciers that can impact human life in multiple ways (Milner et al., 2017). Glacier wastage has accelerated worldwide since the second half of the 20th century. This global trend is attributed to climatic warming (Maria Shahgedanova, 2021). Glaciers across most polar and mountain regions have a negative mass balance dominated by surface melt.

HKHK mountain region spans over 2400 kilometers and has ice of 60,000 square kilometers. According to an estimate outside the polar region, HKHK has more water storage than any other region (Mani et al., 2021). HKHK is vital to people directly and indirectly because it supports the ecosystem and helps

people secure food, energy, and water for their daily lives (Wester et al., 2019). However, there is an indication that the HKHK region is losing its snow cover rapidly. Ice loss in the Himalayas is much more than in other places (Lee et al., 2021, p. 1). HKHK region is an example of how anthropogenic climate change impacts the lives and livelihood of local people who rely on glaciers for food security and energy resources. The early melting of the ice and glaciers is causing water scarcity in South Asia, one of the world's most populated regions (UNESCO, UN-WATER, 2020). The sustainable existence of HKHK glaciers is the security of water and food in the South Asian region. More than 500 million people in the region do not have access to modern energy resources, and meanwhile, the growing population needs constant access to water and food (Rasul & Sharma, 2015). In this situation, the rapid melting of the HKHK glacier may severely hurt the regional government's efforts to ensure their people's sustainable lives.

The glaciers in South Asia are crucial for ecological purposes and the key source of rivers that significantly impact the people's economy, culture, and livelihood. Glaciers feed rivers, and rivers feed crops and agriculture production in the region. Glaciers are an essential component of the hydrologic system in South Asia, and their predictable flow impacts energy and agriculture production (Mani et al., 2021). Any noticeable change in the flow of rivers can affect the ecosystem and the economy of the region. Some significant impacts of rapid glacier melting are visible in communities associated with tourism and society structure (Milner et al., 2019). A recent study from the World Bank has noted that continuous increases in temperature and changes in the pattern of monsoon rains could compromise the living standards of half of the population at the regional level by 2050 (Mani et al., 2018). One of the most obvious adverse effects of the rapid melting of the glacier is water scarcity.

South-Asia is already facing water scarcity, and the unusual melting of the glacier can worsen the water situation in the region. By 2050, around a large population of the world's population will face severe water shortage (UNESCO, UN-WATER, 2020). Regarding water security, almost all countries in the Himalayan region are vulnerable. However, Pakistan is predominantly in a critical spot because of a massive decrease in per capita water availability in the last seven decades. In Pakistan, water per head has declined from 5000 cubic meters per annum to 1000 cubic meters, indicating that this quantity will further decline (Jalil et al., 2018). Himalaya's countries face a severe water crisis as their freshwater withdrawal is more than their resources. HKHK is a crucial source of fresh water in the region, and the glacier's rapid melting may hurt the beneficiary countries' capabilities to store water, channel water, and use fresh water for food and agriculture.

Moreover, water flow from the glaciers is a crucial source of hydropower. In the short term, overflow or floods due to the melting of the glaciers will harm hydropower infrastructure. The melting of the glaciers and reduction in the flow of water from glaciers will seriously compromise energy security in the South Asian region (Mani et al., 2021). In the long run, due to thinning glaciers, the downstream water flow will reduce the required amount for energy production, hurting industry and economic activities. For example, in some South Asian countries, mountain and glacier-based tourism is an important economic component. For example, tourism's contribution to Bhutan's GDP is 15% (Mani et al., 2021). Glaciers attract many visitors and tourists and contribute to the local economy. The melting of the glaciers can hurt the local economy. There have been cases where the local community considered wrapping up glaciers to avoid rapid melting to protect tourism (Moore et al., 2020). The economic impacts of the melting of glaciers in South Asia are multifaceted.

In addition to that, climate-induced glacier melting will also seriously hurt agriculture in South Asia. Agriculture consumes 90% of water, and 20% goes to energy in the region (Mani et al., 2021). It is a significant challenge in the HKHK region to ensure more and more water supply (while resources are depleting) for the cultivation of wheat, rice, and other crops in the presence of increased energy prices (Sharma & Rasul, 2015). The risk is twofold; on the one hand, the unpredictability of downstream water supply due to glacier melting will negatively affect crop production, and on the other hand, the growing population in South Asia will need more food supply. According to an estimate, 14.9 percent of South Asia suffers from undernourishment, which indicates that this trend will increase further (FAO, 2019). In this situation, melting glaciers in the HKHK region can cause food insecurity, which may increase undernourishment and adversely impact the capabilities of the people in the region to live a quality life

One potential result of the cascade effect of glacier melting is flooding, which disproportionately affects poor people in South Asia. According to an estimate, "in August 2017 alone, intense monsoon rains affected 40 million people in Bangladesh, India, and Nepal, claiming nearly 1,300 lives and putting 1.1 million people in relief camps. Floods could cost South Asia as much as US \$ 215 billion annually by 2030" (UNESCO, UN-WATER, 2020). GLOF is a similar disaster associated with glacier melting. GLOF is an abrupt release of a large amount of water retained in a glacial lake, irrespective of the cause. Extreme peak discharges characterize GLOFs, often several times above the maximum discharges of hydrometeorological-induced floods, with an exceptional erosion/transport potential; therefore, they can turn into flow-type movements, e.g., GLOF-induced debris flows (UN-Spider,

2023). Due to floods and other climate-related disasters, many people migrate to South Asia, and these numbers will likely increase over time.

Approaches to and Feasibility of Targeted Geoengineering in the HKHK Region

The critical question is whether we can conceptualize an engineering technique for slowing down ice loss in the Himalayas, just like the Arctic. This section offers a more concise assessment of the feasibility of intervention options regarding targeted geoengineering in the HKHK region. When asked about the potential engineering solution for the HKHK region to curtail the melting of the glaciers, an interviewee (N) responded to this inquiry:

It (HKHK refreezing) would be quite a different approach than the things that we have written about (the Arctic freezing) because the main threats are collapsing of the ice sheets because of increased ocean melting. Obviously, there is no ocean melting in the Himalayas. There would be the possibility to try to minimize the melting of important glaciers in terms of water supply, for example, to communities. But if you were trying to do something for the hundred thousand glaciers in high mountains of Asia, it would be impossible to do by covering with insulating blankets, etc. You would be looking at actually doing some kind of solar radiation management.

Some studies suggest that SAI may help to lower temperature in summer and subsequently preserve glaciers in the HKHK region; however, SAI alone is not enough, and to attain a sufficient level of results for temperature control, there need to be significant emission cuts and GHG removal (Zhao et al., 2017). There are indications that scholars from Asia are interested in exploring the possibilities and impacts of SAI on transboundary water bodies (Delina, 2020). However, there is skepticism that even with aggressive geoengineering, including SRM, there will be a significant change in the melting of glaciers in Asia by 2069 (Zhao et al., 2017, p. 6560). Some examples exist in which scientists and local people preserve the local environment. For example, in some parts of Switzerland, an attempt has been made to wrap glaciers to protect them from sunlight and subsequent melting (Bachmann, 2018). A study has confirmed the effectiveness of SPF ICE in addressing glacier melting, and this cost-effective solution presents a promising opportunity to combat this pressing environmental issue (Prabu, 2022). Scholars have explored that technology of artificially increasing the albedo of glacial ice using highly reflective hollow glass microspheres or other benign reflective materials originally proposed for the

Arctic glacier can be used for the preservation of Himalayan glaciers (Bhattacharyya et al., 2022). However, these local examples need further research to assess their viability in the context of the HKHK region.

One option is ice restoration, a geoengineering method aimed at artificially cooling regions to mitigate glacier melt. Techniques employed in this approach aim to protect and stabilize the ice cover utilizing engineered snow and ice to replenish glacial mass. First is the initial concept regarding Forest Management to Enhance Snowpack Retention, which involves strategically thinning dense forests to create canopy gaps. This process enables greater snow accumulation and prolongs snowpack duration. Research indicates that this approach can effectively increase snow depth and extend the longevity of snowpack, ultimately benefiting downstream water resources (Dickerson-Lange et al., 2021).

Next, Snow fencing and windbreaks are crucial interventions in regions susceptible to wind erosion and snow loss. The Snow fencing and windbreak through which installing physical barriers can reduce wind speed and promote snow deposition in targeted areas, helping to maintain snow cover in regions prone to wind erosion (Crivelli, 2023). By strategically installing physical barriers, these measures significantly reduce wind speed, enabling snow to deposit in targeted areas. This approach not only mitigates wind-induced erosion but also ensures sustained snow cover, which is essential for maintaining ecological balance and preventing resource depletion in vulnerable regions. Snow fencing, often constructed from wood, metal, or synthetic materials, operates by disrupting wind flow, causing snow to accumulate on the leeward side. Similarly, windbreaks, typically made from rows of trees or shrubs, act as natural barriers that enhance soil stability and promote microclimate improvements.

Artificial snowmaking is done by utilizing snowmaking equipment that can supplement natural snowfall, particularly in ski resorts and critical watersheds. However, this method is energy-intensive and may need to be more sustainable on a large scale. The process involves spraying a mixture of water and compressed air through specialized snow guns or cannons, which then crystallize into snow under cold temperatures. Artificial snow is widely used in ski resorts to maintain slopes and extend the ski season, supporting tourism-dependent economies. Beyond recreation, artificial snowmaking has potential applications in mitigating the effects of climate change. For instance, it can help sustain water supplies in snow-dependent regions by supplementing snowpacks, which act as natural reservoirs, releasing water gradually during warmer months. However, the practice has significant

limitations. It is energy-intensive, requiring substantial electricity and water resources, which can strain local ecosystems and contribute to greenhouse gas emissions if powered by non-renewable sources. Moreover, its scalability is limited by the availability of cold temperatures, making it less viable as a large-scale solution in warmer or rapidly warming regions. While artificial snowmaking offers short-term benefits for maintaining economic activities and supporting water needs, it is not a substitute for addressing the broader challenges of climate change and glacier retreat. Instead, it should be considered part of a comprehensive approach that includes conservation, sustainable resource management, and climate mitigation strategies.

A similar approach has gained public attention in Ladakh. Artificial glacier-making in Ladakh, an innovative technique pioneered by environmentalist Sonam Wangchuk, contributes to glacier preservation and sustainable water management. Known as "ice stupas," these cone-shaped ice structures are created by spraying water during winter into freezing air, allowing it to form towering ice formations (Gupta, 2024). These artificial glaciers store excess winter water, which gradually melts in the spring and summer months, providing a steady water supply for agriculture in arid regions. By alleviating the pressure on natural glaciers for water resources, ice stupas indirectly contribute to glacier preservation, reducing overdependence and mitigating the impact of climate change-induced glacier retreat. Furthermore, this technique raises awareness about the urgency of glacier conservation and fosters community participation in adaptive climate strategies, ensuring both environmental sustainability and local resilience in the high-altitude desert ecosystem of Ladakh.

Ice restoration may be viable in select areas to slow glacial retreat, but its long-term effectiveness and environmental ramifications necessitate further investigation. Additionally, logistical challenges, including access to remote locations and the potential ecological disruption caused by artificial installations, pose significant obstacles. Restoring ice in mountain regions is a complex challenge due to the multifaceted impacts of climate change.

Cloud seeding represents another innovative approach to address precipitation deficits, involving the dispersion of substances like silver iodide or sodium chloride into the atmosphere to stimulate precipitation. This technique has been employed to enhance snowfall in specific regions, particularly those facing water shortages or reduced snowpack levels critical for agriculture and water resources. While cloud seeding holds promise for mitigating some climate-induced challenges, its efficacy remains a topic of scientific investigation, with ongoing studies assessing its long-term environmental

impacts and viability. While cloud seeding has been used to enhance snowfall, its effectiveness and environmental impacts are still under study (Hosansky, 2020).

Glacier covering is an emerging technique aimed at mitigating glacial melting. Covering glacier surfaces with reflective materials, such as white geotextiles, can reduce melting by reflecting solar radiation (Herreid & Pellicciotti, 2020). These coverings act as shields, reflecting solar radiation and reducing heat absorption, thereby slowing the melting process. This method has been successfully implemented on a small scale in the European Alps, where it has helped preserve glacier ice during critical summer months. By mitigating ice loss, glacier covering contributes to glaciers' longevity and supports downstream water availability and ecosystem health. However, challenges such as scalability, cost, and long-term environmental impacts remain areas of active research, necessitating further studies to assess its feasibility for broader application.

Protecting glaciers involves various strategies, but they share common challenges, particularly with scaling up. Most approaches are limited to local applications, which fall short given the urgent and widespread nature of glacier melt. Effective interventions must be designed for regional and global implementation to address these escalating risks (Huss, 2024). Moreover, logistical complexities, high costs, and potential environmental impacts pose significant obstacles to broader adoption. In the HKHK region, there is a pressing need for sustainable, regionally focused solutions to preserve the critical ice mass.

Regional solar geoengineering options, such as SAI, MCB, and cirrus cloud thinning, offer promising avenues for addressing these challenges. While primarily studied in polar contexts, these methods show potential for glacier preservation at larger scales (Duffey et al., 2023). Despite the optimism surrounding these innovative approaches, significant research gaps remain, necessitating further exploration to assess their feasibility, risks, and benefits before real-world deployment (Duffey et al., 2023).

The option of local climate modification can be explored in the HKHK region. Targeted SRM techniques, such as SAI, could be implemented on a smaller scale in certain regions to lower regional temperatures (Fox, 2024). This way can help slow the melting of glaciers. Regarding feasibility in the Himalayas, SAI could reduce temperatures and mitigate glacier melt, thereby decreasing water-related risks downstream. However, significant uncertainties exist regarding how such interventions might affect local climate systems, particularly the monsoon, which is vital for South Asian agriculture.

Altering the monsoon could have severe repercussions for millions of individuals who rely on seasonal rainfall for their livelihoods.

MCB involves injecting sea salt particles into the atmosphere to enhance cloud reflectivity, producing a cooling effect on the Earth's surface (Argonne National Laboratory, 2024). While this method has been primarily proposed for oceanic regions to mitigate global warming, its feasibility in the Himalayan context is significantly constrained by the region's landlocked geography. However, adaptations of land-based cloud-brightening techniques could warrant further exploration. A key challenge lies in the complexity of local weather systems. The Himalayas are deeply influenced by monsoon patterns, and interventions like MCB risk unintended consequences, such as disruptions to these critical weather cycles. While MCB may be technically viable on a localized scale, the associated environmental and social risks, particularly in such a sensitive region, highlight the need for cautious consideration and thorough impact assessments.

Moreover, black carbon is producing a determinantal effect on the existence and preservation of Himalayan glaciers. The control and reduction of black carbon can help to protect the Himalayan glaciers. "Black carbon has a much shorter atmospheric lifetime than carbon dioxide (days versus centuries), so reducing emissions produces a much quicker climate response and could buy time for carbon dioxide reductions to take effect" (Bodansky & Hunt, 2020, p. 604). Cutting GHG emissions will indirectly help limit the melting of the glaciers; however, that will be a prolonged process (Bodansky & Hunt, 2020). The preservation of glaciers in the HKHK region can be pursued in multiple forms: adaptation, mitigation, and targeted geoengineering. Still, it is upon South Asian scientists and policymakers to research and deliberate the best course of action.

Targeted geoengineering in the Himalayas could potentially provide temporary relief from glacier melt. While its feasibility is constrained by intricate environmental, social, and political factors, strategies such as regional-scale solar radiation management and ice restoration techniques hold potential. These potential solutions, when carefully considered and implemented, could play a significant role in mitigating the effects of climate change. In alignment with Sen's capability approach, any geoengineering initiative must prioritize equity, inclusive processes, and the capabilities of the most affected populations, ensuring that these communities are empowered to make decisions regarding interventions that directly affect their well-being.

South Asia's Readiness for Targeted Geoengineering and The Role of China

This section will discuss the potential and capacity of South Asian countries and China to pursue targeted geoengineering in the HKHK region. The experts from South Asia interviewed for this study acknowledged that they have a basic understanding of CGE (global SRM and targeted geoengineering); however, scholars and policymakers in the region need an in-depth knowledge of CGE. Almost all interviewees agreed that a better understanding of CGE would be better for national governments as it will increase their capacity to negotiate better at the international level regarding CGE. A better understanding of CGE can enable policymakers to structure better research and governance policies at a national and regional level. An interviewee (M) stated:

The other part is, of course, where I think it is important for us to make these kinds of, or engage in this kind of discussion, is that without building the capacity of our negotiators or scientists or researchers on these aspects, just bringing them onto the table, would not help much. It will be just used to get the sort of their testimony or approval.

The participants believed that more research on issues like CGE could benefit developing countries that have regularly raised the issue of capacity and technical support at COPs. It is pertinent to mention that very few initiatives concerning CGE in South Asia have been taken. However, these initiatives have sensitized the experts and policymakers concerning CGE's role as a potential climate policy option. An interviewee (M) was "aware of at least two research projects funded by the SRMGI" in a South Asian country about solar (not targeted) geoengineering. These instances indicated that the role of civil society and academia is crucial in generating knowledge among scholars and policymakers and raising awareness among the masses. The participants were aware of China's SRM research program and how researchers and academicians benefitted from these programs by getting knowledge about SRM and relating it to the specific context of their native countries. The informants also emphasized the role of universities and scholars with expertise in CGE. The interviewees argued that more scholarships from the Western universities in CGE could help the developing countries increase their capacity regarding negotiations on CGE at international forums.

There is growing interest in CGE research in South Asian countries from scholars and policymakers. An interviewee (N) stated, "I guess it is becoming less of a taboo subject, more of a general kind of a tool in the box that can be on the table in discussions. I guess that it is very much a sort of double-

sided tool. It can be a threat, or it can also be an opportunity.” In this situation, there could be multiple reasons for developing countries to pursue a CGE research program, i.e., to know how risky it is or how it can help them avoid catastrophic climate disasters. The informants were open to CGE research if climate-induced disasters threaten their existence and if CGE can help them address some of the risks posed by climate change. An interviewee(N) said that, regarding CGE, we should be “looking at things either for the greater good of people or the greater good of the climate or at least the greater increase in human knowledge.” It is like a climate emergency in the region. Moreover, a significant impetus for South Asian countries to pursue targeted geoengineering research is China’s geoengineering program. On sociopolitical grounds, researching SRM could trigger a competitive political dynamic that would compel countries to match one another’s efforts out of fear of being left behind (Maas & Comardicea, 2013; Grasso, 2019, p. 218). China is one of the few countries in the world and probably only one amongst developing countries that has started a dedicated SRM research program at Beijing Normal University. There are initial indications that Chinese institutions are trying to protect the glaciers through artificial means:

The experiment, a joint undertaking between the State Key Laboratory of Cryospheric Science (SKLC) and the Dagu Glacier Scenic Area Bureau, drew media attention. The local Chengdu Commercial Daily described it as China’s first attempt to use “geoengineering” to reduce glacier melting, saying that if the results were good, the approach would be optimised and applied elsewhere (Zizhu, 2021).

China's plan to replace mitigation actions with SRM can modify global environmental governance (Edney & Symons, 2014). The role and approach of China’s CGE program are critical for understanding the future of CGE research programs in many developing countries for two reasons. First, G77+ China has remained a unified negotiation group in COPs and usually has argued the issue of climate change collectively from the perspective of all developing countries. Secondly, within the global South, a few countries like India and China have a dominant role because of their economic and technological superiority. In case of any south-south cooperation for the CGE research program, the role of China and India will be crucial. An interviewee (M) argued that “India and China are much more advanced compared to the other South Asian nations.” This situation can lead to a scenario where technologically less-developed nations in the region rely on countries like China and India for CGE research. A study has found greater acceptance of SRM in Chinese respondents. In research, the:

Chinese respondents, for example, indicated greater acceptance for SRM than their North American and European counterparts. The regression analyses on acceptance of SRM by country revealed that lower acceptability ratings for SRM in Canada and Europe were mostly related to stronger beliefs that SRM tampers with nature. Chinese respondents, by contrast, were more accepting of SRM when they held stronger beliefs that it may reduce the motivation to adopt burdensome climate change mitigation efforts (Visschers et al., 2017).

However, there are certain apprehensions in the Western world about China's SRM research program, like whether China would prefer to pursue or deploy SRM technology to offset its emissions unilaterally. An interviewee (N) familiar with the Chinese SRM research program stated, "That is not the impression I get. I mean, I do not think there is any political view in China that wants to use geoengineering to somehow offset emissions increases or unilateral deployment for domestic purposes." However, the interviewees noted a desire amongst the policymakers of China to learn more about SRM. An interviewee (N) commented about the willingness of Chinese policymakers to geoengineering research and stated that:

Well, in terms of understanding what it might mean (SRM)? Yes, absolutely. They (Chinese) are interested in it because, obviously, this is something that many other countries are looking at now and something that is going to increase funding as well, internationally. So, at the highest levels, there is certainly an interest in every aspect of geoengineering, for sure. I think at the lower levels, the actual academic research in universities, I think there is much less understanding about the importance of geoengineering research and not a lot of very good understanding even about much climate research either, to be honest.

How Chinese political leadership perceives CGE as a climate policy instrument will profoundly impact many developing countries' understanding of CGE. China has taken some scientific and knowledge-related initiatives in which it has assumed a leadership role for some developing countries under the Belt and Road Initiative (BRI). One of the most notable initiatives concerning climate change is the Alliance for International Science Organisation (ANSO), through which China invests heavily to improve the capacity of scholars, scientists, and researchers from partner developing countries (Interviewee-Q). Through ANSO, a south-south collaboration concerning glacier protection is a possible option.

China's experience with weather modification techniques positions it as a potential leader in targeted CGE research, particularly in developing Asian countries seeking partnerships to address region-specific climate challenges. With an established institutional framework and technical expertise in weather modification, China is well-placed to expand these capabilities into large-scale CGE initiatives (Bluemling et al., 2019). This experience legitimizes China's role in exploring and potentially leading CGE programs, including glacier preservation efforts in high-altitude regions such as the HKHK region. While unilateral actions by China on glaciers within host countries carry sovereignty and governance risks, cooperative approaches under the BRI present an opportunity for joint research and deployment of CGE technologies. China's political influence, financial capacity, and technological edge provide it with a distinct advantage over Western nations in advancing CGE initiatives regionally and globally. In regions like ASEAN, where no single nation is likely to emerge as a leader in geoengineering research, China's transnational financial and geopolitical reach offers a pathway for collaboration (Lin, 2015). Furthermore, China's investment in South Asian countries under the BRI, including technology and energy transfers, makes it an ideal partner for advancing CGE research and deployment. Few nations possess the technological and financial capacity to execute expensive and complex CGE projects, and China stands out as one of them (Humphreys, 2011; Nassiry et al., 2017). With a strategic interest in greening the BRI, China has both the motivation and capability to drive CGE initiatives forward. Scholars suggest that China will play a dual role in CGE governance: supporting multilateral mechanisms while maintaining a distinct position representing developing nations (Edney & Symons, 2014; Cao et al., 2015). This role will likely be shaped by principles such as CBDR and concerns about Western domination in global negotiations (Edney & Symons, 2014). Additionally, China's role as an alternative donor without stringent conditionalities enhances its appeal to developing countries seeking CGE partnerships (Xing, 2018). With ongoing financial commitments, including a US\$3 million investment and dedicated scientific talent, China is leading one of the world's most ambitious CGE research programs (Temple, 2017). This positions China as a key actor in advancing targeted geoengineering as a development strategy, offering a unique blend of technological capability, financial support, and political legitimacy to address regional and global climate challenges.

Role of the Capability Framework Regarding Targeted Geoengineering in the HKHK Region

Targeted geoengineering, particularly in the sensitive and crucial Himalayan region, presents a promising avenue for addressing climate impacts such as glacial melt. These strategies, which may include approaches like small-scale SRM or ice restoration, have the potential to bring about positive changes, provided they are thoroughly evaluated using the capability framework to ensure effective and equitable interventions.

The objective quadrant of the framework encompasses elements such as Well-being, Development, and Protective Security. The primary aim of targeted geoengineering initiatives in the Himalayas is to enhance the well-being of populations that depend on glacial melt for their water supply, agricultural activities, and energy production. Protecting glaciers from melting is vital for ensuring long-term water availability for millions of downstream people, reflecting the security principle (Drenkhan et al., 2022). Additionally, these interventions should foster sustainable development by ensuring that technological solutions positively impact local and regional economies while avoiding environmental harm or social disruption.

The Process quadrant encompasses democratic principles, informed consent, and free agency. When implementing geoengineering solutions in the Himalayas, it is crucial to uphold democratic values and secure the informed consent of the communities directly affected by these interventions. Informed consent is vital for fostering trust and ensuring that actions are viewed as constructive solutions rather than imposed threats (Sen, 2009). Given that the Himalayas traverse multiple countries, specifically Pakistan, India, Nepal, and China, each with distinct cultural, environmental, and political contexts, local populations must retain the agency to determine how these technologies are applied. This approach ensures that interventions do not disrupt traditional livelihoods, including agriculture.

The Institutions and Governance quadrant highlights the significance of Self-Governance, Fiduciary Duty, and the Impartial Spectator principle. Effective governance is paramount in geoengineering in the Himalayas because of the potential outcomes of targeted geoengineering and the geopolitical nature of certain regional issues. The institutions involved must uphold their fiduciary duty by prioritizing the well-being of the communities most affected, particularly those reliant on glacial water. Given that the Himalayas constitute a transboundary region fostering regional cooperation is crucial. By implementing self-governance mechanisms through the capability approach, local

communities can be empowered to oversee the deployment and monitoring of certain initiatives (Binder & Binder, 2016). Additionally, adherence to the impartial spectator principle ensures that interventions are equitable, preventing the interests of powerful nations from undermining those of vulnerable mountain communities.

The outcome quadrant centers on Enhanced Justice, an Informational Base, and the Eyes of Mankind. The primary objective of geoengineering interventions in the Himalayas should be to cultivate a greater sense of justice, ensuring that these actions benefit the most vulnerable populations affected by glacial melt and climate change rather than amplifying existing inequalities. The capability approach offers a basis for assessing climate policy options' role and contribution to the environmental justice movement (Cañizares-Gaztelu et al., 2024). Therefore, it is crucial to establish a robust informational foundation, which includes conducting comprehensive environmental and social impact assessments to determine unintended consequences, such as disruptions to regional weather patterns. The global community, often called the 'Eyes of Mankind,' is essential in recognizing that these initiatives are not merely local interventions but part of a broader global endeavor to achieve climate objectives and protect vital water resources and ecosystems upon which millions depend.

The capability framework provides an ethical and comprehensive guide for evaluating both adaptation efforts and targeted geoengineering initiatives, emphasizing human well-being, equity, and justice as central principles. It advocates for inclusive processes, institutional accountability, and outcomes that enhance capabilities at local, regional, and global levels. In the context of disaster management, the framework focuses on building resilience and reducing vulnerabilities through democratic and community-driven approaches that empower local populations to actively shape their futures. When applied to targeted geoengineering in the HKHK region, the framework stresses the importance of context-sensitive technological interventions, ensuring they prioritize the needs of the most vulnerable populations and are governed by transparent and equitable institutions that center human and environmental well-being. Through the lens of the capability approach, technological interventions are evaluated not just for their technical efficacy but also for their ethical integrity and contribution to a just, resilient, and sustainable world. This case study explores whether targeted CGE can be effectively recognized as a form of development and examines how such a characterization could increase its relevance in addressing regional climate vulnerabilities. Additionally, it considers whether the essential attributes of justice, inclusivity, and sustainability are present in the HKHK

glacier preservation context. While this analysis remains speculative and does not focus on specific initiatives like the BRI, it offers a conceptual foundation for understanding how the capability framework can define key features of a glacier preservation program aligned with the developmental objectives of a just-targeted geoengineering proposal in South Asia.

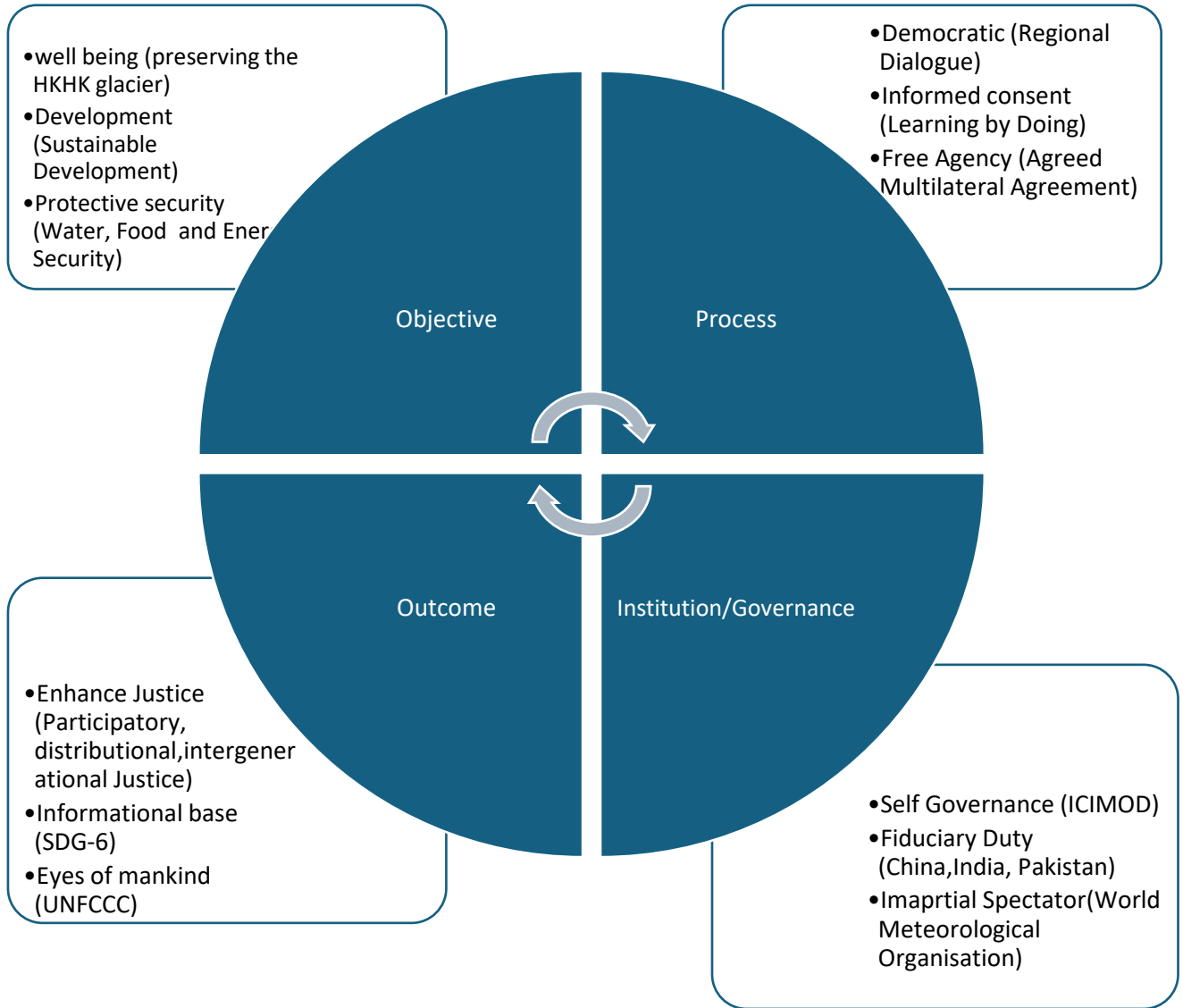


Figure 5: Capability framework for just Targeted geoengineering in South Asia

Objective

The objective stage of the framework aims to determine the main purpose of a geoengineering initiative and evaluate whether it aligns with Sen's concept of development. The primary aim of the capability framework at the objective stage is to thoroughly examine the motivations behind seeking out a targeted geoengineering initiative and to determine its compatibility with Sen's overarching concept of development. The objective of the targeted geoengineering concerning HKHK is the preservation of HKHK glaciers in the wake of climate change, which is closely related to the concept of development through well-being in the capability approach. Sen's idea of development is a departure from the traditional concept of development, which relies on income as the central criterion of human well-being. One of the most prominent rationales of Sen's departure from income-based well-being is its failure to consider human diversity (Sen, 1999). This diversity can include age, physical strength, and environmental or geographical circumstances. These diversities enable or restrict people to utilize their income and attain quality of life. When we look at the HKHK region, the sustainability of HKHK glaciers can be crucial in the lives of billions of people who rely on these glaciers for water, food, and energy security. This way, the targeted intervention in the HKHK region for protecting human capabilities that are directly attached to glaciers' sustainability is in line with the well-being argument of the capability approach. The preservation of HKHK glaciers can help attain sustainable development in South Asia, especially in areas reliant on sustainable water supply. The capability approach endorses this peculiar type of development, advocating removing all obstacles that put people in economic or social poverty.

Development requires the removal of major sources of unfreedom: poverty as well as tyranny, poor economic opportunities as well as systematic social deprivation, neglect of public facilities as well as intolerance or overactivity of repressive states (Sen, 1999, p.3).

Looking at development from a capability perspective helps to approach HKHK glaciers as a transnational asset for the South Asian region. The sustainable existence of HKHK glaciers can boost social and economic conditions for the poor people of South Asia. South Asia is a water-scarce region, and floods often cause destruction. Sustainable provision of water through HKHK glaciers can lead to food and energy security in the region. Suppose water scarcity and flooding can be managed by limiting the undesired melting of HKHK glaciers through targeted geoengineering. In that case, targeted geoengineering will enhance the protective security of the inhabitants of the regions. One important thing to understand is that human miseries are of various types; therefore, human needs

vary depending on the nature of the challenges humans face in a region or country (Sen, 1999, p. 154). For water-scarce regions like South Asia, sustainable provision of water and adaptation in the wake of water-related disasters like floods is about advancing and protecting human capabilities. Water is important for sustainable development and its role is crucial for human security (UN, 2023). Sustainable water management by preserving the HKHK glaciers must be seen as a social arrangement where human capabilities can thrive. For example, a person who earns a constant income through a job and lives in the foothills of the Himalayas experiences a flash flood, and her home disappears. Her income may remain the same after the flood, but her level of development at pre- and post-flood levels will not be similar. Sen argues that social arrangements are not only vital for determining the quality of life but also for converting income into a capability:

Handicaps, such as age or disability or illness, reduce one's ability to earn an income. But they also make it harder to convert income into capability, since an older, or more disabled or more seriously ill person may need more income (for assistance, for prosthetics, for treatment) to achieve the same functionings (even if that achievement were, in fact, at all possible). Thus real poverty (in terms of capability deprivation) can easily be much more intense than we can deduce from income data (Sen, 2009, p.256).

The capability approach looks at a sustainable environment as a meta-capability that enables people to live a quality life instead of just looking at rain patterns or humidity. In this context, climate policy options like adaptation, mitigation, and targeted geoengineering can also be analyzed as a resource to protect and advance human development in the wake of anthropogenic climate change. The idea of CGE complementing existing climate policy options is close to the capability framework's concept of "positive social changes." Social changes like health and education bring economic changes and boost economic activity (Sen, 1999, pp. 259-260). If targeted CGE can act as part of the social development plan for preserving glaciers and avoiding floods and droughts. In that case, it can contribute to the economic development of people suffering from anthropogenic climate change. This framing of the objective in line with Sen's idea of development significantly differs from the traditional concepts about global SRM or targeted geoengineering. Generally, the prime objective of geoengineering options is to restrict the global average temperature without contextualizing these initiatives' development and well-being outcomes.

Processes

The process stage of just CGE emphasizes democracy, informed consent, and free agency as core elements for ethical and effective decision-making. It highlights the importance of inclusive participation, transparent consultation mechanisms, and accountability across national, local, and regional levels. For initiatives like preserving the HKHK glaciers, international collaboration and stakeholder engagement are essential to ensure diverse perspectives are considered. This approach aligns with Amartya Sen's emphasis on procedural fairness, fostering transparency, equity, and balanced governance in implementing targeted geoengineering projects.

A democratic process lies at the core of the capability approach, emphasizing that both the procedures and the real opportunities available to individuals are crucial for achieving justice (Sen, 2009, p.297). Democracy, in this context, holds both intrinsic and instrumental value, particularly in relation to Nussbaum's ten central capabilities, such as control over one's environment. As Drydyk (2020, p.671) notes, "People who cannot participate in such political and economic choices are not living as well as those who can." Sen advocates for embedding democratic values even in autocratic regimes, arguing that they enhance responsiveness to citizens' needs and prevent disasters like famines. In the context of targeted geoengineering, democratic participation ensures interventions are designed and implemented transparently, reflecting public reasoning and avoiding the pitfalls of purely market-based approaches (Scholte, 2010). However, Sen does not detail the exact mechanisms for obtaining public opinions on environmental issues, leaving space for regional cooperation platforms such as the South Asian Association for Regional Cooperation (SAARC) or the BRI to facilitate open debates among South Asian nations on targeted geoengineering.

Informed consent is equally critical in the governance of targeted geoengineering, requiring stakeholders to be knowledgeable, competent, and capable of making decisions based on adequate information. According to the capability approach, knowledge and education are essential social opportunities, empowering communities to actively shape their destinies (Sen, 1999). This perspective is particularly relevant in culturally and economically diverse regions such as the HKHK, where vulnerabilities vary significantly across different communities. Moreover, targeted geoengineering solutions are highly context-dependent, differing in scale, risk, effectiveness, and governance structures. Localized techniques, such as reflective covers or snow fences, address specific challenges in confined areas with manageable risks, while regional interventions, such as SAI or MCB, operate on broader scales with far-reaching environmental, social, and political implications. Achieving meaningful consent and governance for these interventions requires inclusive, transparent,

and participatory decision-making processes. As Sen suggests, political freedom must underpin such governance frameworks, preventing dominance by powerful interest groups and encouraging public deliberation across borders (Sen, 2009, pp.140–141). His “learning-from-doing” approach aligns with the experimental nature of targeted geoengineering, advocating iterative improvements based on past successes and failures (Sen, 1999, p.255). In this way, the capability approach provides both ethical and practical guidance for developing legitimate, context-sensitive, and effective targeted geoengineering strategies in vulnerable regions like the HKHK. Sen explicitly talks about the joint interests of groups, like shared transboundary resources that can be better served by placing an effective mechanism with practical social norms:

The real world is full of a great many problems of this kind, varying from environmental sustainability and the preservation of shared natural resources ('the commons') to work ethics in production processes and civic sense in urban living. In dealing with such situations, there are two grandways of bringing about the attainment of mutual benefits through cooperation, namely agreed contracts that can be enforced, and social norms that may work voluntarily in that direction (Sen, 2009, pp. 202-203).

Developing countries can provide meaningful consent to targeted geoengineering in the HKHK region if they possess the necessary knowledge and research capabilities. These social opportunities can be enhanced through effective public policy and inclusive participation frameworks. Developing countries often emphasize that responses to climate change must adhere to the principle of equity and common but differentiated responsibilities and respective capabilities (CBDR-RC), reflecting national circumstances. In this context, creating an enabling environment rooted in participatory governance becomes essential for informed decision-making about targeted geoengineering.

The capability framework underscores the interdependence of various freedoms, placing free agency at the heart of development. Free agency is particularly vital for vulnerable communities and developing countries striving for climate justice. Policymakers in South Asia are responsible for assessing the role and relevance of targeted geoengineering in the HKHK region, as these interventions have far-reaching implications for future generations. Sen's framework holds policymakers accountable for acts of commission and omission in preventing avoidable disasters (Sen, 1999, p.171). A multilateral, regional agreement grounded in shared aspirations and scientific cooperation could strengthen collaboration among South Asian nations (Shrestha & Bhadra, 2019). By adopting Senian principles of inclusivity, equity, and transparency, targeted geoengineering

initiatives in the HKHK region can better address the climate justice concerns of developing countries while ensuring participatory and accountable governance.

Institutions/Governance

The institution/governance stage of the framework focuses on the governance of targeted geoengineering, emphasizing the roles of institutions and forums at local, national, regional, and international levels. Governance encompasses standardization, regulation, monitoring, evaluation, and verification, distinguishing it from processes, which refer to the methodologies and decision-making procedures institutions employ. Institutions, such as the UNFCCC, provide overarching policy frameworks, while processes involve negotiations, stakeholder consultations, and implementation strategies. Effective governance addresses key questions, including financing, risk management, transparency, autonomy, decision-making, and cooperation, requiring an integrated strategy that combines scientific rigor, ethical considerations, and stakeholder engagement. This stage also aligns with Amartya Sen's capability framework, where participatory governance is central to addressing injustice and promoting collective action. Sen emphasizes that while participatory governance has its limitations, it remains one of the most effective approaches for tackling behavioral challenges and fostering inclusive decision-making in complex policy environments.

The critics of democracy – no matter how vigorous they may be in their rejection – must find some way of addressing the deep attraction of participatory governance, which is of continuing relevance today, and is hard to eradicate (Sen, 2009, p. 323)

The electoral processes in the democracy enable the ordinary people to scrutinize their leaders and policies, which is an empowerment of the masses. That is why Sen argues that effective democracy and participatory governance have successfully dealt with issues of famine (Sen, 2009). While dealing with issues of global importance with local implications, Sen favors regional deliberation, which can ensure the effective participation of stakeholders. Sen is against global-level interventions because any such conception of global justice will require establishing a global sovereign state, which is nearly impossible given the existing division of nation-states (Sen, 2009, p. 25). This argument of Sen supports regional or targeted geoengineering compared to global-level SRM.

The governance of CGE is a tricky subject, and the interviewees had varied ideas about how to govern better targeted in South Asia. The respondents approached the issue of governance from multiple angles ranging from finance to technical expertise and to increase the capacity of developing countries to negotiate better and argue their case equitably. Two aspects of

governance at an institutional level are pretty evident in the interviewees' responses: the role of the United Nations Security Council in dealing with the security aspect of CGE and limiting the divide between the global North and global South regarding technical and financial capability for CGE research.

Given China's dominant role in South Asia, the governance of targeted geoengineering is a crucial issue. The multistakeholder dialogue (MCSD), traditionally used for the regulatory framework and intergovernmental dialogue on various regional and global issues, could also be used for the anticipatory governance of CGE (Conca, 2019). "ACEMSD might push forward anticipatory governance of CE by promoting social learning, sharpening and legitimizing governance norms, and starting to arrange the political space for governance by states" (Conca, 2019, p.417). Moreover, certain norms and established principles of international environmental law may be relevant to targeted geoengineering's future in South Asia. One possible implication of targeted geoengineering research activity is transboundary harm. A fundamental principle of international environmental law is a duty to prevent transboundary pollution (Bodnasky & Hunt, 2020, p. 613). In the trial Smelter case, it was observed:

No state has the right to use or permit the use of its territory in such a manner as to cause injury ... in or to the territory of another or the properties or persons therein, when the case is of serious consequence.

The duty to prevent transboundary harm has been reflected in many international conventions and treaties like Principle 21 of the Stockholm Declaration on the Human Environment (later reiterated in Principle 2 of the Rio Declaration on Environment and Development). This principle provides that States have 'the responsibility to ensure that activities within their jurisdiction and control do not cause damage to the environment of ... areas beyond the limits of national jurisdiction' (Bodnasky & Hunt, 2020, p. 613). Then, in various of its judgments, the International Court of Justice (ICJ) referred to this principle to emphasize the "duty of due diligence" requirement of Environmental Impact Assessment (EIA) as part of the procedural duty to avoid transnational harm (Bodnasky & Hunt, 2020). In addition, the Environmental Modification Convention (ENMOD) was signed in 1978, prohibiting weather modification techniques for military and warfare purposes. CBD also bans a specific form of climate engineering like ocean fertilization.

A certain level of cooperation in targeted geoengineering governance is a prerequisite. International cooperation is essential because the cost of misunderstanding or uncertainty is enormous in the case

of large-scale geoengineering deployment (Dalby, 2015; Grasso, 2019; SRMGI, 2011). Unlike CDR, which has more national-level implications, SRM or glacier geoengineering may have regional or global implications. Due to potential negative implications of SRM like ozone depletion, change in temperature and precipitation, and diffusion of incoming light, SRM can hurt human well-being, especially those people who are already vulnerable and have limited capacity (Grasso, 2019, p.2018, Suarez and van Aalst, 2017). The situation becomes even more complex when “it is often claimed that SG is an exacting technology that must be repeated regularly indefinitely’ (Pierrehumbert, 2017). Therefore, the governance of targeted geoengineering in South Asia is an important question, given the high political tensions among the neighboring states and the stakes involved in control over the HKHK region as the primary source of freshwater discharge.

Given the urgency of climate challenges and the existence of many institutions, it would be appropriate to examine the feasibility and relevance of existing institutions for the governance of CGE (Graso, 2019, p. 221). There are debates about the possible governance of global geoengineering techniques under the umbrella of UNFCCC, but it does not seem very easy because of the nature of environmental politics (Bodansky & Hunt, 2020). The following section will discuss existing regional institutions with potential CGE governance mechanisms.

There are many options for the governance of SRM and targeted engineering research in South Asia. However, given the political fault lines in the region, each option needs to be evaluated carefully. Each governance option may have long-term implications for the region and the research and deployment of CGE. There could be a need for joint research work and infrastructure development for CGE (like a Research Station for glacier engineering) and data sharing from the respective member states.

A possible governance option for South Asian countries for targeted geoengineering is under Chinese BRI. Except for India, almost all South Asian countries are also part of the BRI. BRI provides a governance framework for technological and knowledge sharing in a transnational manner. China sponsors BRI, one of the few countries globally with the technological and financial capability to initiate large-scale climate-geoengineering projects. China, India, and Pakistan are the three most populous states of the Himalayan region, and they may have a genuine interest in protecting the HKHK glaciers through a collaborative effort, as all of them highly rely on HKHK for freshwater that is crucial for their agriculture and food security. China’s research program on geoengineering shows China’s willingness to advance research in the CGE field. The respondents had reservations about the option of BRI as a research platform for CGE research in South Asia. An informant (Q) praised BRI as a platform

for researchers and scientists for member countries of BRI but at the same time acknowledged that this platform is subject to criticism due to various factors. One of the concerns about BRI's role as a center for CGE research is this forum's geopolitical dimension, as countries that are politically not aligned with China may not receive fair treatment in this forum (Interviewee-M).

Assessing the required governance features is crucial when exploring a glacier preservation project in the HKHK region. Are the BRI or associated organizations in favor of such an endeavor? One important consideration is whether, as a leader, China's BRI should establish an equitable partnership for a glacier preservation project. The difficulty is that the BRI is very transactional - based on mutual benefit, and ultimately linked to China's economic expansion through trade relations. It is hard to see glacier preservation as fitting into this mold.

Another possible forum for CGE governance, especially for glacier engineering in South Asia, is the International Centre for Integrated Mountain Development (ICIMOD). One organization praised by almost all the interviewees concerning glacier engineering due to its technical expertise and significant work in the field is ICIMOD, based in Nepal. An interviewee (M) stated that ICIMOD is "also located close to the Himalayas. They are probably appropriately capacitated to conduct this research (glacier engineering)." ICIMOD is an intergovernmental agency for knowledge sharing among the member countries of HKHK. There are eight member countries of the ICIMOD – Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal, and Pakistan. One advantage of ICIMOD is that it can carry out similar transnational projects in regional member countries (RMCs). ICIMOD receives funding from its core member countries, non-regional member countries, and various bilateral and multilateral donors categorized into programmatic, strategic and project funding. ICIMOD, in its annual report, has outlined six urgent actions as main objectives:

- (i) Cooperate at all levels across the HKH region for sustainable and mutual benefits.
- (ii) Take accelerated actions to achieve the SDGs and the nine mountain priorities.
- (iii) Recognize and prioritize the uniqueness of the HKH mountain people
- (iv) Promote regional data and information sharing and science and knowledge cooperation
- (v) Enhance ecosystem resilience and halt biodiversity loss and land degradation
- (vi) Take concerted climate action at all levels to keep global warming to 1.5°C by 2100

In October 2020, during the first HKH Ministerial Mountain Summit, ministers from all eight member countries signed a declaration to strengthen regional cooperation in the HKH, which emphasized “on mountain environments and livelihoods, and to assess the feasibility of establishing a regional institutional mechanism” (ICIMOD-webpage). An important initiative of ICIMOD is the establishment of The Hindu Kush Himalayan Monitoring and Assessment Programme (HIMAP), which blends scientific and policy knowledge. Over 350 researchers and practitioners worked on this program and jointly produced the first assessment report. The report, directly and indirectly, discusses issues related to climate change like energy, cryosphere (frozen water), water, food security, air pollution, disaster and resilience, poverty, adaptation, gender, and migration. The assessment report will provide for evidence-based decision-making concerning environmental affairs in the region. (Wester et al., 2019, p. VII). Given the expertise of ICIMOD in mountain and glacier studies, it appears that ICIMOD can provide a platform for research of targeted geoengineering, especially for the protection of glaciers in the region.

The South Asian Association for Regional Cooperation (SAARC) is the third option to govern targeted geoengineering in the HKHK region. SAARC has eight member countries: Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, and Sri Lanka. SAARC was established in Nepal and has a secretariat in Kathmandu, Nepal. One primary objective of SAARC is “to promote the welfare of the peoples of South Asia and to improve their quality of life; to accelerate economic growth” (SAARC, 2020). Moreover, SAARC aims to promote collaboration in technical and scientific areas that can benefit CGE research in the region. However, one challenging aspect is that the SAARC charter prefers to make decisions unanimously and avoid discussing contentious issues. Due to this reason, for the last many years, SAARC has failed to take any notable initiative regarding transnational issues like climate change.

South Asia Co-operative Environment Programme (SACEP) is another forum for targeted geoengineering research as SACEP aims to promote regional cooperation in South Asia in the field of environment. SACEP member countries are Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, and Sri Lanka, and it was established in 1982. SACEP also aims to support the conservation and management of the region's natural resources and work closely with all national, regional, and international institutions, governmental and nongovernmental experts, and groups engaged in such cooperation and conservation efforts. SACEP supports the national government's efforts for environmental protection and sustainable development. Since its creation, SACEP has implemented

many projects and programs in environmental education, environment legislation, biodiversity, air pollution, and the protection and management of the coastal environment. SACEP is also the secretariat for the South Asian Seas Programme.

A key governance question for targeted geoengineering is determining financial and technical responsibility, particularly given the risks of this intervention. The capability framework advocates for social security systems as risk mitigation tools to address uncertainties and potential harms (Sen, 2009, pp. 167–168). South Asian economies like China, India, and Pakistan could collaborate to create a regional fund for targeted geoengineering research and risk management. Additionally, Article 8 of the Paris Agreement, particularly clause 8(4)(f) on climate risk pooling, offers guidance on financing and cooperation mechanisms for managing climate risks. The fiduciary duty of the global North is also reflected in Article 8, emphasizing loss and damage responsibilities and the need for cooperation among parties. Developing countries often lack the financial resources for geoengineering research, and interviewees in our study emphasized that the global North should bear a significant share of the financial burden, recognizing their historical responsibility for climate change. As one interviewee (N) noted:

I have argued that it should be those rich countries that actually make the investment to do that. And to a large degree, that is about protecting the global South. The farmers in Bangladesh and or other affected persons clearly are not responsible for glacier melt and will meet much worse outcomes.

This observation about the responsibilities of the rich countries is in line with the idea of the fiduciary duty of Sen in the capability approach, which looks to vulnerability and capacity, in addition to causation, as a basis for responsibility. When respondents were asked about the existing financial commitments, they expressed dissatisfaction because developed countries have failed to generate \$100 billion committed under the Paris Agreement, which was raised to 300 billion in Nov. 2024.

An interviewee (M) suggested that developing countries continuously receive new deadlines concerning climate finance, and developing countries are unsure if developed countries will follow these deadlines. Regarding the mechanism for financial support for CGE research, the interviewees supported the idea that UNFCCC is a suitable forum. An interviewee (M) suggested, "I think finance has to flow through UNFCCC to give the appropriate platform for the governments and others to participate." The participants believed that the finance for CGE research should enhance the

capacity of government officials, researchers, and academics from developing countries as it will serve their nations in the long run (Interviewee-M). The respondents believed that the allocation of finance for climate change research in developing countries is not always based on the financial strength of a country. Sometimes, these decisions have political connotations, and political ownership of sensitive programs like CGE research is a prerequisite to making these programs successful and sustainable (Interviewee-O).

However, while dealing with the governance of targeted geoengineering, where monitoring, reporting, and verification are of immense importance, who will act as a neutral monitor? Since targeted geoengineering in HKHK would involve several scientific experiments and their verification and validity, it would be viable if an international agency with a scientific capacity could monitor and verify these results can act as an independent observer. That is why transparency is a critical concern for developing countries, especially given their limited research capacity about targeted geoengineering. An interviewee (M) stated:

Transparency is the most important thing in this particular aspect, specifically for solar radiation management, because there is much concern about this thing. The one thing worse that you can do is do a covert operation, and that is only going to make people more suspicious. So whatever they do, whether it is research or deployment, they have to be utmost transparent.

Sen believes that some institutions in the global governance framework have been created to address complex issues. It would be prudent if the existing institutions could be used to address transnational challenges (Sen, 2009, p.408). Sen discusses Adam Smith's idea of an "impartial spectator" to address the issue of fairness. Targeted geoengineering can be beneficial and detrimental depending on its nature, extent and scientific verifications. In the case of targeted geoengineering in the HKHK region, the World Meteorological Organization (WMO) can play a role in MRV for targeted geoengineering in the HKHK region. The mandate of WMO is:

As weather, climate and the water cycle know no national boundaries, international cooperation at a global scale is essential to implement an Earth system approach for the development of meteorology, climatology, operational hydrology and related environmental services as well as to reap the benefits from their application. WMO provides the framework for such international cooperation.

The World Climate Research Programme (WCRP) has launched a Lighthouse Activity (LHA) on Climate Intervention Research, and WMO is a partner in this initiative. Governance of any transboundary subject is inherently complex; therefore, research and governance of targeted geoengineering in HKHK will involve multiple institutions and actors.

This section outlines a governance framework for glacier preservation, emphasizing the need to align institutional mandates, technological capabilities, and developmental goals with the unique challenges of high-altitude ecosystems like the HKHK region. Institutions such as ICIMOD emerge as particularly relevant, given their regional focus on knowledge sharing, policy coordination, and sustainable mountain development. ICIMOD's ability to bridge scientific research, policy formulation, and on-the-ground implementation positions it as a key facilitator for targeted glacier preservation initiatives, addressing critical issues like cross-border water security and climate adaptation. In contrast, broader initiatives like the BRI, while valuable in infrastructure and environmental projects, often fall short in addressing the localized and context-specific needs of glacier conservation due to their top-down governance model and geopolitical focus. The framework advocates for a nuanced approach that leverages ICIMOD's strengths in regional cooperation while integrating targeted technologies suited for both localized interventions and regional strategies. By prioritizing scale flexibility and fostering community participation, this governance model ensures responsiveness to the diverse challenges posed by glacier melt, offering a comprehensive pathway to address both developmental and ecological risks in vulnerable mountain regions.

Outcome

The final stage of the capability framework evaluates the success or failure of targeted geoengineering projects based on principles of justice, accountability, and measurable contributions to climate resilience. Sen's capability approach emphasizes promoting justice and reducing preventable injustices, treating disasters like floods and droughts caused by anthropogenic climate change as injustices if they could have been avoided through proactive measures (Sen, 2009, p.4). In the HKHK region, targeted geoengineering must aim to enhance climate justice by ensuring participatory, distributional, and intergenerational equity. Respondents highlighted the importance of precaution and transparency in research and implementation due to the inherent uncertainties and risks associated with SRM. As one interviewee (M) noted, stakeholders in South Asia “do not want to happen without appropriate information. We go down the road of solar radiation management and make it (climate change) even worse for us.” The broader climate justice debate underscores historical

inequalities, where developed countries have disproportionately benefited from industrialization while developing countries continue to bear the brunt of rising emissions and subsequent disasters. Respondents expressed skepticism about developed countries' willingness to fulfill financial and technical responsibilities, given past failures to honor commitments under. Governance structures for targeted geoengineering must, therefore, be rooted in time-tested principles of climate justice, avoiding moral hazards where developed nations or large corporations exploit these technologies as a license to continue emissions without prioritizing sustainable development. Effective governance in the HKHK region will require inclusive decision-making, community participation, and clear accountability mechanisms to prevent exploitation and ensure that targeted geoengineering serves as a tool for reducing climate injustice rather than perpetuating existing inequalities. In this context, a robust institutional framework is essential for aligning targeted geoengineering initiatives with principles of equity, transparency, and long-term sustainability.

Moreover, an appropriate informational base can help precisely determine whether a targeted geoengineering policy or intervention has helped enhance climate justice. Sen's idea of diversified poverty instead of solely focusing on income is based on an informational base of human capabilities (Sen, 1999). Regarding targeted geoengineering in the HKHK region, SDG-6 (Clean water and sanitation) can be an appropriate informational base. As a targeted intervention in the HKHK region will address the fast melting of glaciers and profoundly impact water availability, management, and utilization in South Asia, SDG-6 can provide an informational base for evaluating the outcome of targeted geoengineering in the HKHK region. Some of the targets under SDG-6 can be of significant relevance regarding the sustainability of HKHK glaciers, like:

- 6.5 - By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate
- 6.6 -By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes
- 6. A -By 2030, expand international cooperation and capacity-building support to developing countries in water- and sanitation-related activities and programmes, including water harvesting, desalination, water efficiency, wastewater treatment, recycling and reuse technologies

These SDGs can be effectively translated into the context of glacier preservation by setting clear and actionable targets. For example, protecting the most vulnerable glaciers by 2030 and achieving a measurable reduction in glacial melt by a specified amount are goals that align with SDG principles. Establishing such targets is crucial for creating a credible framework that prioritizes accountability and progress. This approach not only emphasizes the urgency of addressing glacier melt but also provides a structured pathway for achieving meaningful environmental and developmental outcomes.

The question of who should be entrusted with a fair assessment of targeted geoengineering outcomes is critical, especially given the transnational implications for human and environmental security. According to Amartya Sen, fairness in assessing an act or policy can be guided by the principle of evaluation through the “eyes of mankind”—a perspective that encourages empathetic policymaking and recognizes the potential for inadvertent consequences affecting vulnerable populations (Sen, 2009). In the case of targeted geoengineering in the HKHK region, where the stakes are high, the United Nations (UN) emerges as the most suitable institution to provide this global evaluative perspective. Specifically, the UNFCCC can play a decisive role in initiating, monitoring, or halting targeted geoengineering initiatives based on thorough assessments. The UNFCCC's unique position as a global platform allows it to act as the “eyes of mankind,” offering oversight rooted in inclusivity, equity, and scientific evidence. Various UN-affiliated organizations have already highlighted the urgency of addressing glacier melt and the governance of geoengineering technologies. For instance, UNESCO warns that 50 World Heritage sites containing glaciers could disappear by 2050 but emphasizes that proactive measures could still prevent this outcome (UNESCO, 2022). Similarly, UNEP has called for the establishment of a new regulatory and governance framework to manage technologies such as SRM effectively (UNEP, 2023). These insights underscore the pivotal role of multilateral institutions in ensuring that targeted geoengineering initiatives are evaluated fairly, transparently, and in alignment with global standards for sustainability, equity, and justice.

Conclusion

This analysis examines the role of SRM and glacier preservation as strategies for development, with a particular focus on the HKHK region. It also addresses the governance mechanisms necessary for effective glacier preservation. Targeted SRM approaches, specifically those aimed at glacier conservation, offer potential solutions to critical development challenges posed by glacier melt, including water scarcity, loss of livelihoods, and regional insecurity. Unlike global SRM initiatives,

which often prioritize the interests of developed nations, targeted SRM better aligns with the needs of the global South by addressing localized vulnerabilities. Framing SRM as a development tool highlights its potential for inclusivity and equity, encouraging the global South to engage in discussions about its ethical, technical, and governance dimensions.

A central challenge in glacier preservation lies in designing governance frameworks that are both just and effective. Drawing on the capabilities approach, this chapter emphasizes the importance of agency, equity, and consent in governance arrangements. For localized interventions, governance must prioritize community engagement, financial support, and alignment with local needs. In contrast, regional-scale approaches such as SAI or MCB require cross-border collaboration, robust institutional frameworks, and mechanisms to address transboundary impacts while ensuring equitable outcomes.

Institutions like ICIMOD provide valuable models for facilitating regional cooperation grounded in principles of justice and sustainability. By addressing these governance challenges, glacier preservation efforts can integrate development and climate adaptation, fostering resilience in some of the world's most vulnerable regions. This dual focus on governance and targeted SRM underscores the potential for glacier preservation to play a transformative role in advancing sustainable development and climate resilience.

This chapter addressed two questions regarding targeted climate geoengineering and glacier protection in the HKHK region. First, Why does the discussion around targeted geoengineering need to be framed as a development issue, and how does this framing alter the discussion? In a way, this chapter explores the perspective on climate change and its impact on human capabilities for people living in vulnerable situations. Discussing climate geoengineering as development can help policymakers consider these technology-based climate policy options while focusing more on vulnerable groups' social and economic conditions.

Second, can the preservation of glaciers in the HKHK region through targeted geoengineering be approached in a manner that aligns with Sen's concept of development? Protecting HKHK glaciers through targeted geoengineering can be seen as a development initiative under the capability framework because it protects the energy and water security of the region. Development not only means advancing capabilities but also protecting the existing capabilities under threat due to anthropogenic climate change. HKHK glacier is a crucial source of fresh water for South Asia is melting fast and posing a threat to the life and livelihood of the billions of people in the region who are already

a life below standard human development indicator. A regional and cultural context for targeted geoengineering research in South Asia is essential. HKHK is crucial for the ecosystems and livelihood of hundreds and millions of people in the region and deserves more attention because of climate vulnerability and the dependence of South Asian people on it as a water resource. The climate is changing so rapidly that options like adaptation and mitigation may not be enough to preserve melting glaciers in HKHK. The country's beneficiaries of HKHK may need to seriously consider their preparedness to respond to a situation where the increase in temperature may threaten the HKHK glacier's existence. In this situation capability framework provides a moral and governance compass to look for possible intervention scenarios that can help to protect HKHK glaciers as a shared resource of humanity and advance the human development of South Asian people.

The case study proposes that targeted geoengineering in the HKHK region can be explored to protect the glaciers and improve the well-being of South Asian people. This can lead to sustainable development and achieve the area's food, energy, and water security. The processes involved are complex and delicate, requiring cooperation from various stakeholders and adherence to international environmental law. Engaging all states and establishing joint learning mechanisms would help ensure informed consent in these processes. ICIMOD can serve as a potential platform for regional stakeholders to ensure self-governance. Countries like Pakistan, India, and China need to protect the interests of the HKHK region. The World Meteorological Organization, with its expertise in weather affairs, can act as an impartial observer given the transnational nature of targeted geoengineering.

An important aspect of the case study was ascertaining the acceptance of targeted geoengineering in South Asia. Empirical data suggests that South Asian countries are more open to further research on targeted geoengineering than global SRM as a climate policy approach. However, due to the climate justice movement, these countries are unlikely to engage in any form of CGE deployment program without prior deliberation and thorough research to avoid potential harmful impacts. Increased research collaboration from countries like China and the USA with South Asian countries is crucial. Even if developing countries eventually reject the idea of targeted geoengineering, the decision can be better formulated if developing scientists and policymakers fully understand CGE issues. The case of targeted geoengineering for the HKHK region presents an opportunity for South Asian countries to enhance their research and policy expertise in geoengineering. China and India's technological and financial advancement provides a platform for regional cooperation and south-south geoengineering

collaboration. However, there are significant challenges in the process due to the potential unintended consequences of geoengineering and the unique geopolitical dimensions of the region. For this purpose, a non-political and primarily scientific organization like ICIMOD plays a crucial role in creating and disseminating knowledge that South Asian policymakers can rely on and engage in consultative processes for regional geoengineering.

Chapter 5: Conclusion

This dissertation examines the potential of climate geoengineering as a catalyst for development, addressing fundamental questions about its relationship with development goals in South Asia. Can geoengineering be redefined as a tool for fostering development? If so, what impact might this redefinition have on the broader geoengineering discourse? The objective is to uncover the transformative potential of geoengineering within the development context. The analysis concludes that geoengineering can indeed contribute to development, but its effectiveness depends heavily on how development is defined and the specific circumstances of each country. In the second chapter, Amartya Sen's capability theory is presented as a strong foundation for understanding geoengineering through a development lens. Sen's justice-focused approach moves beyond traditional income-based measures of progress, offering a broader perspective centered on human well-being, freedom, and agency. This framework provides valuable insights into critical geoengineering debates, addressing issues such as risk management, equity, and autonomy. Building on these principles, this chapter proposes a framework rooted in Sen's capability theory and human development values. This framework aims to guide the design and evaluation of geoengineering initiatives, ensuring they align with principles of justice, inclusivity, and sustainable development.

Framing climate geoengineering as a tool for development carries significant implications, particularly for engaging the public in the global South and highlighting its relevance to their daily lives. This perspective shifts the debate away from the polarized views that either portray geoengineering as an existential threat or reduce it to a simplistic technological fix for global warming. Instead, it emphasizes human well-being as the central focus, encouraging a more nuanced understanding of geoengineering as a development pathway. Viewing research on geoengineering as a knowledge-generation activity further strengthens this approach by fostering informed decision-making capabilities. Scholars play an essential role in this process, serving as key contributors to the creation and dissemination of knowledge. Additionally, climate change must be understood as a major source of unfreedom that restricts human capabilities and prevents individuals from leading fulfilling lives. In this context, any viable climate policy option, including geoengineering, should be seen as a means to restore and enhance freedom, creating pathways for development. Eliminating sources of unfreedom—whether they stem from poverty, social exploitation, or authoritarian governance—becomes central to designing effective and just climate policies. By aligning geoengineering initiatives

with these principles, we can ensure they contribute not only to environmental sustainability but also to the broader goal of human development and well-being.

Framing climate geoengineering as a development issue offers a compelling narrative for climate policy in developing countries, where the priority lies in addressing immediate climate challenges such as floods, droughts, and food insecurity, while sustaining long-term economic growth. CDR, when viewed as a tool to boost productivity without increasing carbon emissions, presents an attractive pathway for achieving these dual objectives. However, mitigation has not gained significant traction in many developing countries, where policymakers and scholars often prioritize adaptation strategies to address pressing vulnerabilities. As a result, ambitious measures like CDR are less likely to gain widespread acceptance unless they align directly with the developmental priorities of the global South. Furthermore, financial assistance and technology transfer remain critical prerequisites for implementing such solutions, and the feasibility of these technologies in developing contexts hinges on addressing these two interconnected challenges.

Targeted geoengineering, in particular, holds promise for developing countries by addressing region-specific climate risks, such as the rapid retreat of glaciers in high-altitude regions. This approach offers localized interventions that could yield tangible benefits without requiring the extensive global coordination demanded by large-scale solar radiation management initiatives. However, scholars and policymakers in the global South often lack clarity on the distinctions between solar radiation management and targeted geoengineering, creating gaps in understanding and limiting informed participation in these emerging policy discussions. These knowledge gaps, coupled with limited research and engagement, have fueled skepticism and hesitation regarding the adoption of targeted geoengineering. Nonetheless, there is a prevailing belief in developing nations that any climate policy capable of reducing the impacts of climate-induced disasters while fostering sustained economic and energy development is more appealing than approaches exclusively focused on emission reduction targets set by developed countries. Bridging these gaps in knowledge, financing, and technology transfer will be essential for targeted geoengineering to gain meaningful traction in the global South.

The risks associated with climate geoengineering differ significantly between developed and developing countries, yet these distinctions are often poorly understood by scholars and policymakers from the global North. While equity-based approaches to geoengineering governance frequently highlight the vulnerabilities of developing nations, they rarely address the global North's economic dominance and its historical role in shaping global governance systems. Without acknowledging this

structural imbalance, it becomes challenging to fully comprehend the concept of climate justice and the historical responsibility of developed nations toward the global South. Amartya Sen's capability theory sheds light on this dynamic by revealing how colonial legacies and entrenched inequalities continue to shape global interactions. Sen's childhood example of Kader Mian, a man forced by economic deprivation to risk his life during communal riots, illustrates the lived realities of systemic injustice—an experience often difficult for scholars from affluent nations to grasp. Developing countries, therefore, approach geoengineering initiatives with caution, viewing them through the lens of historical distrust and skepticism about the global North's potential to control and manipulate planetary systems for its benefit. However, it is equally important to recognize the heterogeneity among developing countries, each with distinct environmental concerns and varying capacities to address climate challenges. In global environmental negotiations, developing countries often prioritize developmental concerns and remain wary of technologically ambitious interventions like climate geoengineering, given the historical precedent of power imbalances and broken promises. Sen's capability framework captures these nuances by emphasizing the social and economic disparities that persist in the global South and the structural inequities perpetuated by global governance systems.

Amartya Sen's capability theory offers a compelling framework for analyzing climate geoengineering as a pathway for development. Unlike traditional development theories that focus on economic indicators, Sen's approach emphasizes human well-being, agency, and freedom. Rooted in his observations of systemic failures during famines, Sen argues that crises are not merely the result of resource scarcity but are often caused by poor governance and policy failures. This perspective provides valuable insights into the governance of complex issues such as climate geoengineering, which carries significant ethical, social, and environmental risks. The capability framework encourages a multidimensional perspective on climate change, moving beyond simplistic metrics and embracing solutions that prioritize restoring and enhancing human capabilities. By reframing geoengineering as a developmental tool within this framework, its governance can become more democratic, transparent, and inclusive. This approach ensures that human agency remains central, with decision-makers bearing responsibility not only for current populations but also for future generations. A governance system guided by the capability framework would focus on mitigating risks, ensuring accountability, and establishing robust mechanisms for monitoring, reporting, and verification. Such a system would not only address liability concerns but also provide a foundation for more equitable

and responsible deployment of geoengineering technologies, aligning them with broader goals of sustainable and just development.

The proposed capability framework illustrates how the capability approach can effectively address the multifaceted challenges of climate change. Its application within a CGE context depends on the specific techniques employed and the regional or national characteristics where these techniques are implemented. By integrating development-sensitive principles from the capability framework, a more comprehensive and context-specific research and governance structure can be established, particularly in developing countries. The capability approach moves beyond traditional economic indicators such as Gross National Product (GNP) or income growth, emphasizing a broader view of human well-being and agency. Its practical policy relevance gives it an edge over purely theoretical models, as it has directly influenced significant initiatives such as the United Nations Development Programme's Human Development Index (HDI). These initiatives reflect collaborative knowledge and are widely recognized by global governance actors, including multilateral institutions, non-state actors, and national governments, underscoring the capability approach's applicability to real-world challenges.

In the context of the BRI, the integration of CDR as a climate policy measure could significantly enhance the resilience of recipient nations grappling with increased carbon emissions from infrastructure and development projects. Technological advancements have positioned CDR as a promising climate policy option, particularly within transnational development frameworks like the BRI. Compared to SRM, CDR faces less political resistance, making it a more viable choice for implementation. Developing countries show interest in carbon dioxide removal due to its financial incentives and potential co-benefits, including carbon trading opportunities. However, successful adoption depends on forming partnerships that align with their developmental priorities and respect their unique environmental and socio-economic circumstances. The BRI provides a collaborative platform for host countries to access financial and technical assistance from China, enabling them to integrate carbon dioxide removal into their climate strategies. In the case of Pakistan, China has introduced several initiatives that offer opportunities for future research and collaboration in CDR. Environmental cooperation, disaster risk reduction, and low-cost energy initiatives under the CPEC provide pathways for advancing CDR research. Collaborations with institutions such as the Chinese Academy of Sciences (CAS) allow Pakistani researchers and policymakers to benefit from advanced technological expertise in CCS. Moreover, partnerships facilitated through multilateral institutions like

the World Bank and support from developed nations, including the United States, can further strengthen Pakistan's capacity for CDR research and implementation. These collaborative efforts underscore the potential of transnational initiatives like the BRI to address both developmental and environmental goals through targeted and equitable climate interventions.

The governance structures of the BRI are rooted in the Chinese development model, which may not always align with the emission reduction commitments of host countries under the Paris Agreement. This misalignment underscores the importance of involving international forums such as the UNFCCC to assist developing nations in implementing CDR initiatives in line with global best practices. While the BRI primarily operates as an investment-driven platform, there is a growing need to incorporate principles of justice, capability, protective security, self-governance, and informed consent into its CDR initiatives, following Amartya Sen's capability approach. For meaningful and equitable outcomes, China must work collaboratively with host countries to establish transparent and democratic decision-making processes. Institutions modeled after global platforms like the UNEP could support the BRI countries in achieving these goals. Some CDR technologies, such as reforestation, afforestation, and soil carbon sequestration, already fall partially under the governance of the Conference of the Parties. Furthermore, the decentralized nature of the Paris Agreement allows countries to incorporate CDR strategies into their NDCs to meet emission reduction targets.

In this context, should we prioritize targeted geoengineering as a sustainable development strategy over global SRM? Can initiatives aimed at protecting glaciers in the HKHK region be classified as a legitimate form of development? These questions raise critical governance and policy considerations. While global SRM remains a contentious and politically sensitive option, targeted geoengineering has gained increasing attention in academic discussions. In South Asia, SRM is not currently considered a viable policy option, largely due to concerns about its potential unintended consequences and the limited involvement of developing countries in its governance. Instead, developing nations have shown greater willingness to engage in research and capacity-building efforts to better understand SRM technologies. Targeted geoengineering, on the other hand, is viewed as less risky and more aligned with regional priorities, allowing for direct participation by developing countries in governance and decision-making. Scholars from the global South often frame global SRM as a climate justice issue, cautioning that unilateral action by developed countries could deepen the existing global North-South divide on climate governance.

Targeted geoengineering in the HKHK region, particularly for glacier preservation, presents a compelling opportunity for advancing regional development goals. South Asia has experienced significant economic growth over the past decade, placing immense pressure on its natural resources and fragile ecosystems. Glacier protection initiatives in this region have the potential to address multiple developmental concerns, including energy security, water resource management, and agricultural productivity. This case study explores how protecting glaciers can mitigate the cascading effects of accelerated glacial melt, which threatens regional stability and sustainability. However, it is essential to recognize that targeted geoengineering efforts in the region remain in their infancy. Substantial investment in research, technological feasibility assessments, and governance frameworks is needed before any policy commitments are made. The significance of glaciers in the Hindu Kush Himalayan region cannot be overstated, and stakeholders across South Asia are increasingly aware of their critical role in maintaining ecological and socio-economic stability. Targeted geoengineering represents an opportunity to align environmental protection with regional development priorities, offering a pathway to address both climate resilience and long-term human well-being.

The cooperation of China and India is essential for advancing targeted geoengineering initiatives in South Asia, given their regional influence and technological capacity. International institutions and forums such as the UNFCCC, UNEP, and Degrees Initiative can play a key role in fostering polycentric research and governance for targeted geoengineering. With its technical expertise, ANSO could lead projects focused on preserving glaciers in the HKHK region through geoengineering technologies. However, the region's complex political dynamics present challenges for governance through platforms like the BRI and the SAARC. Local stakeholders emphasize the importance of regional collaboration to protect the livelihoods and well-being of the millions dependent on the glaciers for economic stability, water resources, energy production, and food security. In this regard, the ICIMOD is well-positioned to take on a leadership role. Its deep expertise in glacier studies, regional credibility, and trusted relationships with member countries and international partners make it an ideal platform for advancing targeted geoengineering research and fostering collaboration across borders.

This dissertation contributes to the broader scholarship on climate policy, climate geoengineering, and the capability approach, specifically in the context of developing countries. Its primary contribution lies in contextualizing climate geoengineering as a relevant climate policy option for South Asia by applying the capability approach and examining case studies of the BRI and the HKHK

region. This research bridges the gap between academic scholarship and policymaking, addressing questions frequently raised by scholars and decision-makers in the global South about the feasibility, risks, and opportunities presented by geoengineering. Furthermore, it emphasizes the active role developing countries can play in shaping the geoengineering discourse. Future research can build upon this foundation, particularly in exploring how the capability approach can guide decision-making around emerging technologies, not only in geoengineering but also in artificial intelligence, biotechnology, data science, blockchain and decentralized finance, advanced connectivity technologies, and gene editing. These technologies have the potential to transform human society, but they also present ethical dilemmas and risks. Whether to embrace or reject them requires a robust theoretical framework to guide governance, and the capability approach offers an adaptable model that prioritizes human well-being, agency, and development.

The geopolitical dimensions of SRM and targeted geoengineering also warrant further investigation, particularly in the context of strategic rivalry between global powers like China and the United States. The deployment of such technologies could have unequal regional impacts, potentially influencing global diplomatic relations. Scholars should also examine how nuclear-armed states might approach the governance of climate technologies, drawing lessons from their experiences in managing treaties and risk frameworks for nuclear arms. A key research question emerges: Will these states approach global geoengineering as a matter of national security or as part of their climate policy? Collaboration among regional powers such as China, India, and Pakistan within frameworks like the SAARC or the BRI could mitigate geopolitical tensions while promoting cooperative governance mechanisms. Insights drawn from nuclear governance frameworks could offer valuable lessons for managing the complexities of geoengineering technologies. Ultimately, increased investment in regional research and collaboration will strengthen the capacity of South Asian scholars and policymakers to engage meaningfully in global debates on climate change technologies. This dissertation underscores the importance of grounding geoengineering governance in principles of well-being, development, and autonomy, ensuring these technologies serve as tools for both environmental resilience and social progress.

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