Modeling and Policy of CO₂ Removal from the Atmosphere

An IPCC Perspective on the Challenges for AR5

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• Why Geoengineering?

• Governance Structure and Uncertainty
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- Why Geoengineering?
- Governance Structure and Uncertainty
Anthropogenic drivers of climate change

Population
- Per capita production
  - GDP / Pop
Energy intensity
- E / GDP
Carbon intensity
- CO₂ / E
CO₂ released
- CO₂(A)/CO₂

CO₂ emissions
- Radiative forcing
- Ocean acidification
- Temperature change
- Impacts

Other GHG emissions
Options to mitigate climate change

Population
- Per capita production: GDP / Pop
- Energy intensity: E / GDP
- Radiative forcing

Other GHG emissions
- Agricultural practices etc.

CO₂ emissions
- Carbon cycle
- CO₂ air capture
- Geoengineering
- Radiative forcing
- Ocean acidification
- Temperature change
- Impacts

Increasing energy efficiency
- Non-fossil energy
- CO₂ capture at plant (CCS)
- CO₂ released
- CO₂(A)/CO₂
Options to mitigate climate change

- Population
  - Per capita production
  - Energy intensity
  - Carbon intensity

- CO₂ emissions
  - CO₂ air capture
  - Radiative forcing
  - Geoengineering

- Other GHG emissions
  - Agricultural practices etc.

- Increasing energy efficiency
- Non-fossil energy
- CO₂ capture at plant (CCS)
- CO₂ released

- Carbon cycle
- Ocean acidification
- Temperature change

Impacts
2. We agree that deep cuts in global emissions are required [...] to hold the increase in global temperature below 2 degrees Celsius, ...
12. We call for an assessment [that] would include consideration of strengthening the long-term goal [...] including [...] temperature rises of 1.5 degrees Celsius.
An emerging coalition between geo-engineers and environmentalists?

- Population
  - Per capita production
    - Energy intensity
  - CO₂ emissions

- Other GHG emissions

- Radiative forcing
  - Geoengineering

- Carbon cycle
  - CO₂ air capture
  - CO₂ capture at plant (CCS)

- Ocean acidification
  - Temperature change
   - Limit to 2 / 1.5 °C warming above preindustrial
Implications for the Scenario Process

WG I
Extreme events
Sea level rise

WG II
Differential impacts:
\[ \Delta(2^\circ C/3^\circ C) \]
\[ \Delta(3^\circ C/4^\circ C) \]

WG III
Differential mitigation costs:
\[ \Delta(2^\circ C/3^\circ C) \]
\[ \Delta(3^\circ C/4^\circ C) \]

Complete picture of impact and mitigation costs for policy relevance

\[ \Delta(2^\circ C/3^\circ C), \Delta(3^\circ C/4^\circ C) \]
Policies
Only 6 scenarios from 3 models in the lowest category…

Fisher et al. (2007), AR4
Low Mitigation Scenarios Beyond AR4

- ...but already many more available for AR5
- Exploration of RCP3-PD within the scenario process

Knopf/Luderer/Edenhofer (2011).

~20 scenarios

Negative emissions

Knopf/Luderer/Edenhofer (2011).
Costs of Low Mitigation Scenarios

Knopf/Luderer/Edenhofer, 2001

Somewhere here starts the (model dependent) feasibility frontier
Carbon Air Capture – why?

1. **Introduces new sink to the carbon cycle**
   greater flexibility for CO₂ removal (detached from sources)

2. **Ability to (over)compensate past CO₂ emissions**
   safeguard against unanticipated / ignored climate impacts

**Candidate technologies:**
- Biomass + CCS (BECS)
- Direct air capture using a chemical solvent
- Enhanced weathering (e.g. in-situ carbonation of silicates, ocean alkalinity enhancement)
Direct Air Capture

Technically feasible
  e.g. Lackner & Zeman (Columbia); Keith & Stolaroff (Calgary/CMU), Dubey (Los Alamos), Baciocchi (Mazotti (Rome))
  - energy for CO₂ compression < 10% hydrocarbon energy
  - land area requirement small (> 40 ktC / km²)
  - process experience for simple designs, e.g. in pulp and paper industry

Prototype built by D. Keith, J. Stolaroff, G. Lowry at U Calgary

Direct Air Capture

- Direct air capture pushes the feasibility frontier

- It is probably too expensive to dominate the portfolio of mitigation options

- It is not an emergency option if all other mitigation options fail because of the inertia in the carbon cycle
Science: Scope of options

Goal-setting by policy makers

Biomass + CCS

1.5°C target
2°C target

Consideration of BECS

Science

Data
Biomass + CCS

• BECS could dominate the portfolio of mitigation options

• BECS bears inherent risks for sustainability, side-effects are not well understood

• It could also push the feasibility frontier
Science:
Scope of options

Science
Goal-setting by policy makers

Data

1.5°C target
2°C target

Ocean acidification is not considered!

Radiation Management
Radiation Management

- It could be an emergency option if all other mitigation options fail

- Radiation management bears inherent risks for sustainability, side-effects are not well understood

- It could also push the feasibility frontier, however impacts like ocean acidification cannot be addressed.
Research Questions (I)

• What kind of options are available at what costs and risks?

• Environmental impact of large-scale „geo-engineering“ options?

• What kind of social costs have to be included?
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• Why Geoengineering?

• Governance Structure
Categories of Risk

- **Normal Risks**
  - Scope: Individual, local
  - Intensity: Endurable, reversible
  - Probability: Normal distribution

- **Large Scale but Bounded Risks**
  - Scope: Transnational
  - Intensity: Endurable, reversible/irreversible
  - Probability: Normal distribution

- **Systemic Risks:**
  - Scope: Transnational and transgenerational
  - Intensity: Terminal, irreversible
  - Probability: Fattened tail
Overlapping public good problems: BECS and Direct Air Capture

- Agricultural productivity
- Land-use-management: impact on biodiversity and food security
- Impact on deforestation
Different Technologies, Different Games

- General form: \[ \pi_i = \alpha \cdot Q(x_1, x_2) - C(x_i) \]

  - Good provision technology \( Q(\cdot) \)
    \[ Q(x_1, \ldots, x_N) = \ldots \]
  
  - Unit costs \( C(\cdot) \)
    \[ C(x_i) = c \cdot x_i \]

- Here, we choose
  \[ \alpha = 6, \quad c = 4 \]
Mitigation as a Prisoner’s Dilemma

\[ \pi_i = \alpha \cdot Q(x_1, x_2) - c \cdot x_i \quad \text{with} \quad \alpha = 6, \quad c = 4 \]

- “Average”
  \[ Q(\cdot) = \frac{1}{N} \sum_j x_j \]

- Game structure: Prisoners’ Dilemma
- Nash Eq. different from Social Optimum

→ Similar to Summation
Radiation management as a best-shot game?

\[ \pi_i = \alpha \cdot Q(x_1, x_2) - c \cdot x_i \quad \text{with} \quad \alpha = 6, \quad c = 4 \]

- “Best Shot”
  \[ Q(\cdot) = \max \{x_1, \ldots, x_n\} \]

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<tr>
<td>X1 = 0</td>
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Could radiation management solve the cooperation problem?

\[ \pi_i = \alpha \cdot Q(x_1, x_2) - c \cdot x_i \quad \text{with} \quad \alpha = 6, \quad c = 4 \]

- “Best Shot”
  \[ Q(\cdot) = \max\{x_1, \ldots, x_n\} \]
- Chicken game
- Examples:
  - Breakthrough technologies, research and development
  - Discovering cures
  - Infiltrating terrorist groups
  - Geoengineering
Research Questions (II)

- Management for systemic risks

- Coordination and governance problems of different CDR options (e.g. extensive biomass use)

- Radiation management as a best-shot game?
Thank you for your attention!