johnthescone

Modeling and Policy of CO_2 Removal from the Atmosphere

An IPCC Perspective on the Challenges for AR5

May 30th-31st 2011, CMCC Venice, Italy

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- Governance Structure and Uncertainty

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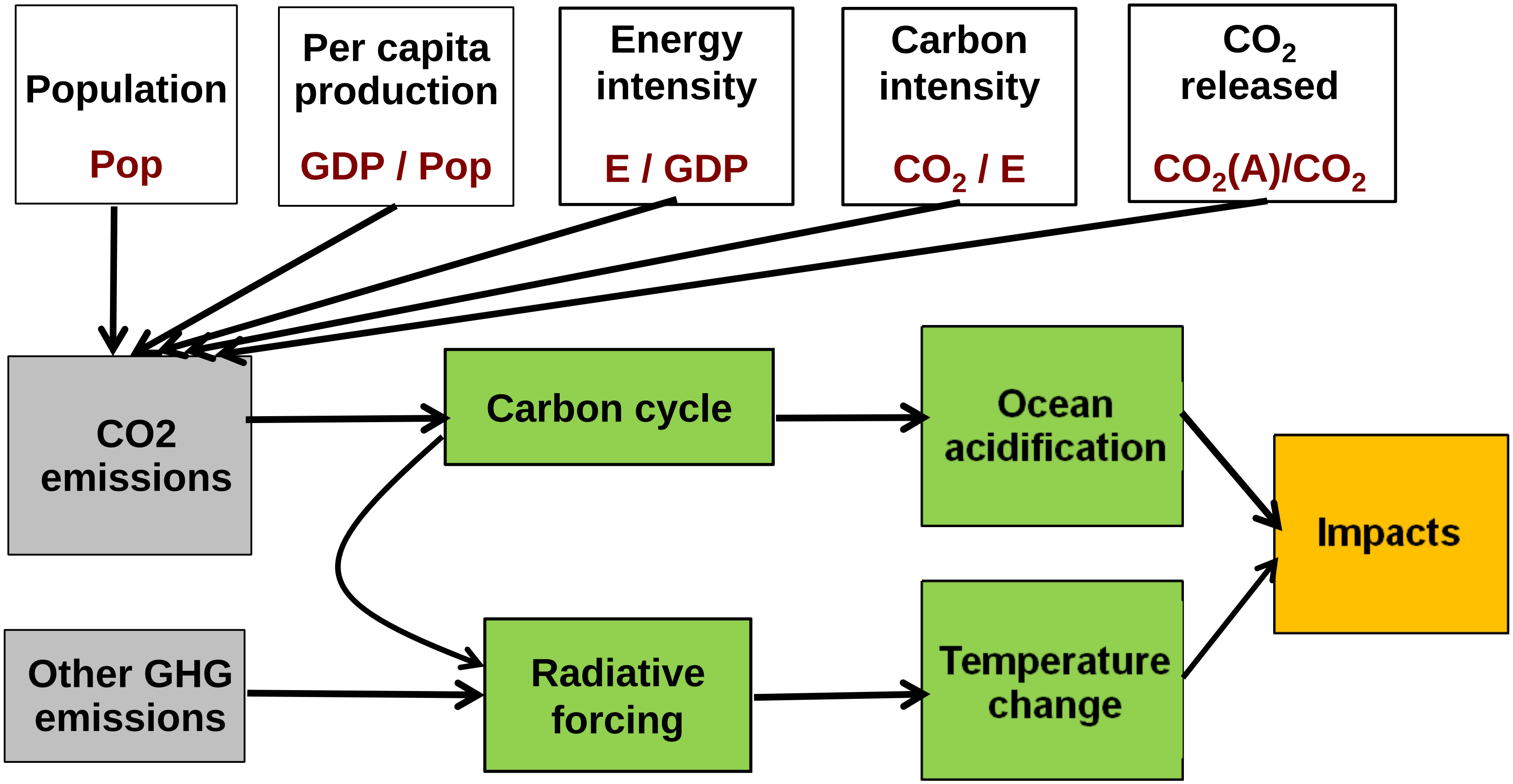
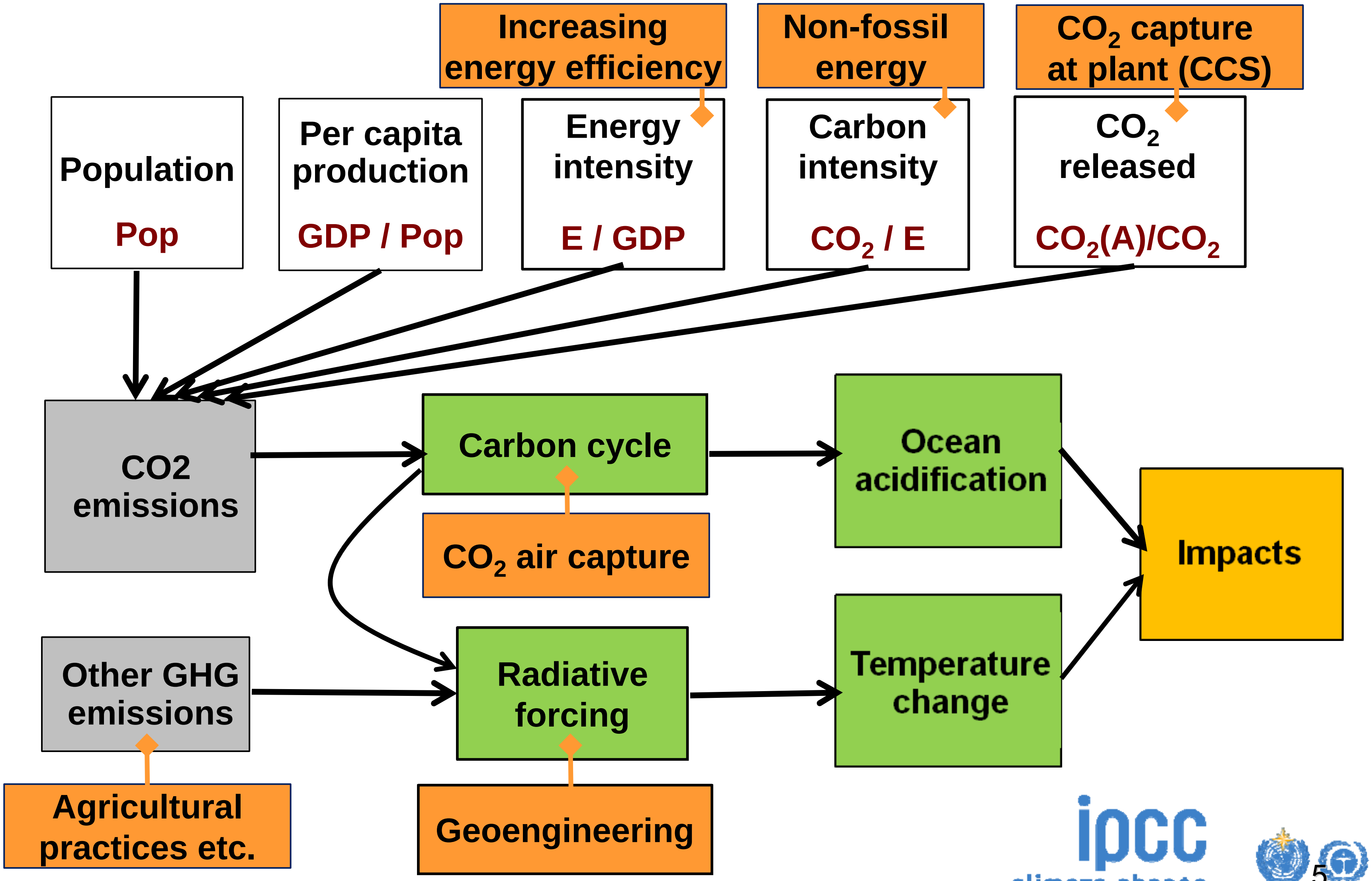
Anthropogenic drivers of climate change



Options to mitigate climate change



Increasing energy efficiency

Non-fossil energy

CO_2 capture at plant (CCS)

Population

Pop

Per capita production

GDP / Pop

Energy intensity

E / GDP

Carbon intensity

CO_2 / E

CO_2 released

$CO_2(A)/CO_2$

CO2 emissions

Carbon cycle

CO_2 air capture

Ocean acidification

Impacts

Other GHG emissions

Radiative forcing

Temperature change

Agricultural practices etc.

Geoengineering

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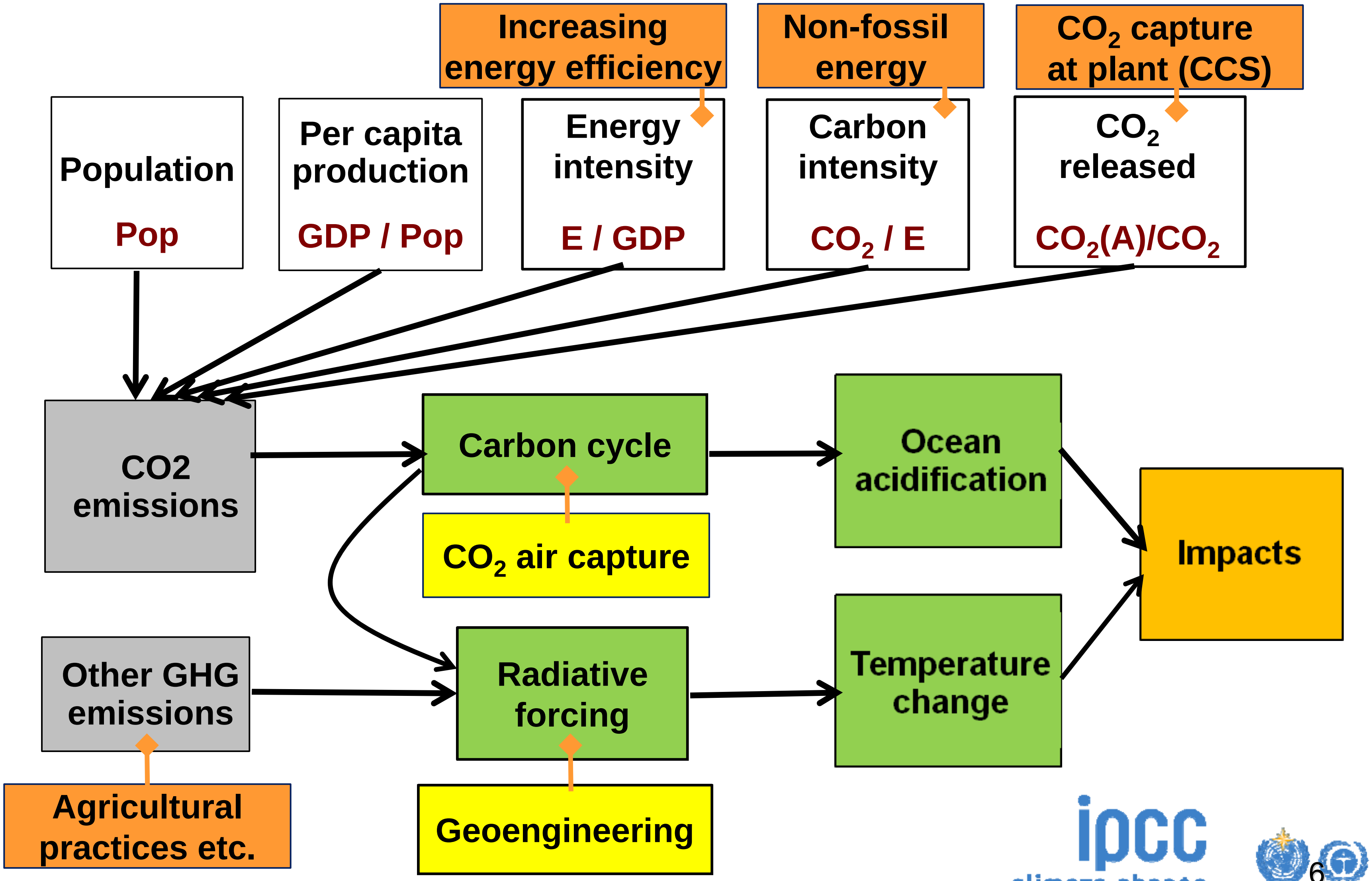
Options to mitigate climate change



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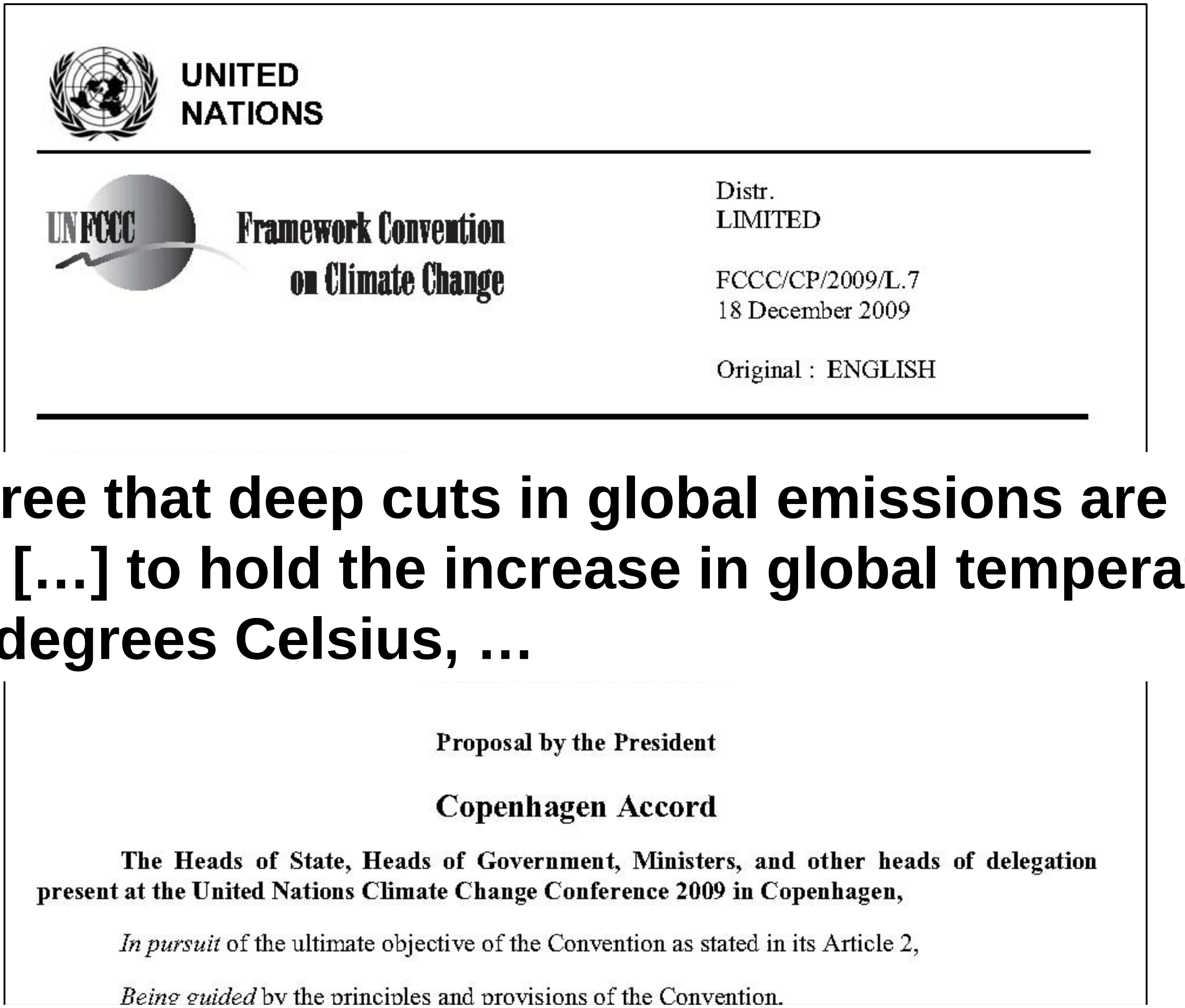
The Policy Arena: The Copenhagen Accord



UNITED
NATIONS

Framework Convention
on Climate Change

Distr.
LIMITED

FCCC/CP/2009/L.7
18 December 2009

Original : ENGLISH

2. We agree that deep cuts in global emissions are required […] to hold the increase in global temperature below 2 degrees Celsius, …

Proposal by the President

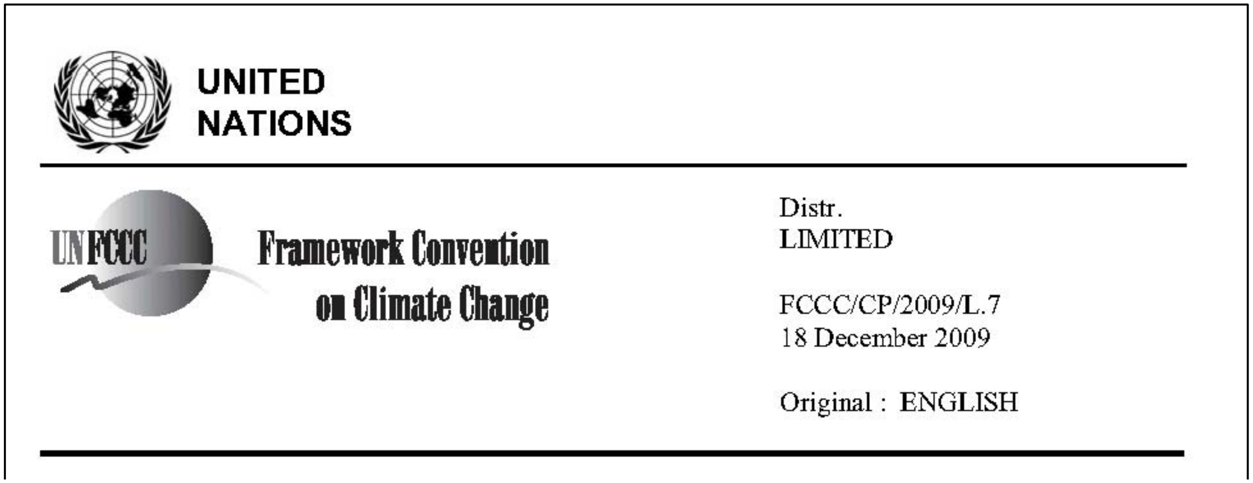
Copenhagen Accord

The Heads of State, Heads of Government, Ministers, and other heads of delegation present at the United Nations Climate Change Conference 2009 in Copenhagen,

In pursuit of the ultimate objective of the Convention as stated in its Article 2,

Being guided by the principles and provisions of the Convention,

The Policy Arena: The Copenhagen Accord



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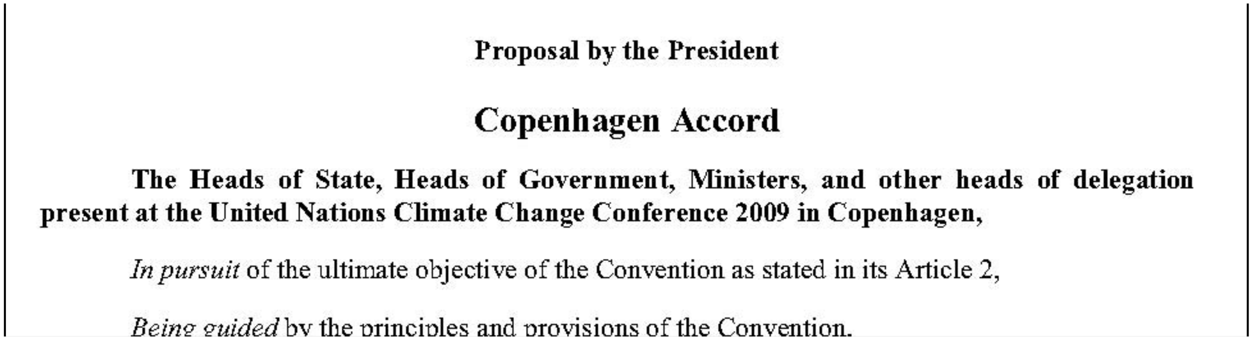
12. We call for an assessment [that] would include consideration of strengthening the long-term goal […] including […] temperature rises of 1.5 degrees Celsius.



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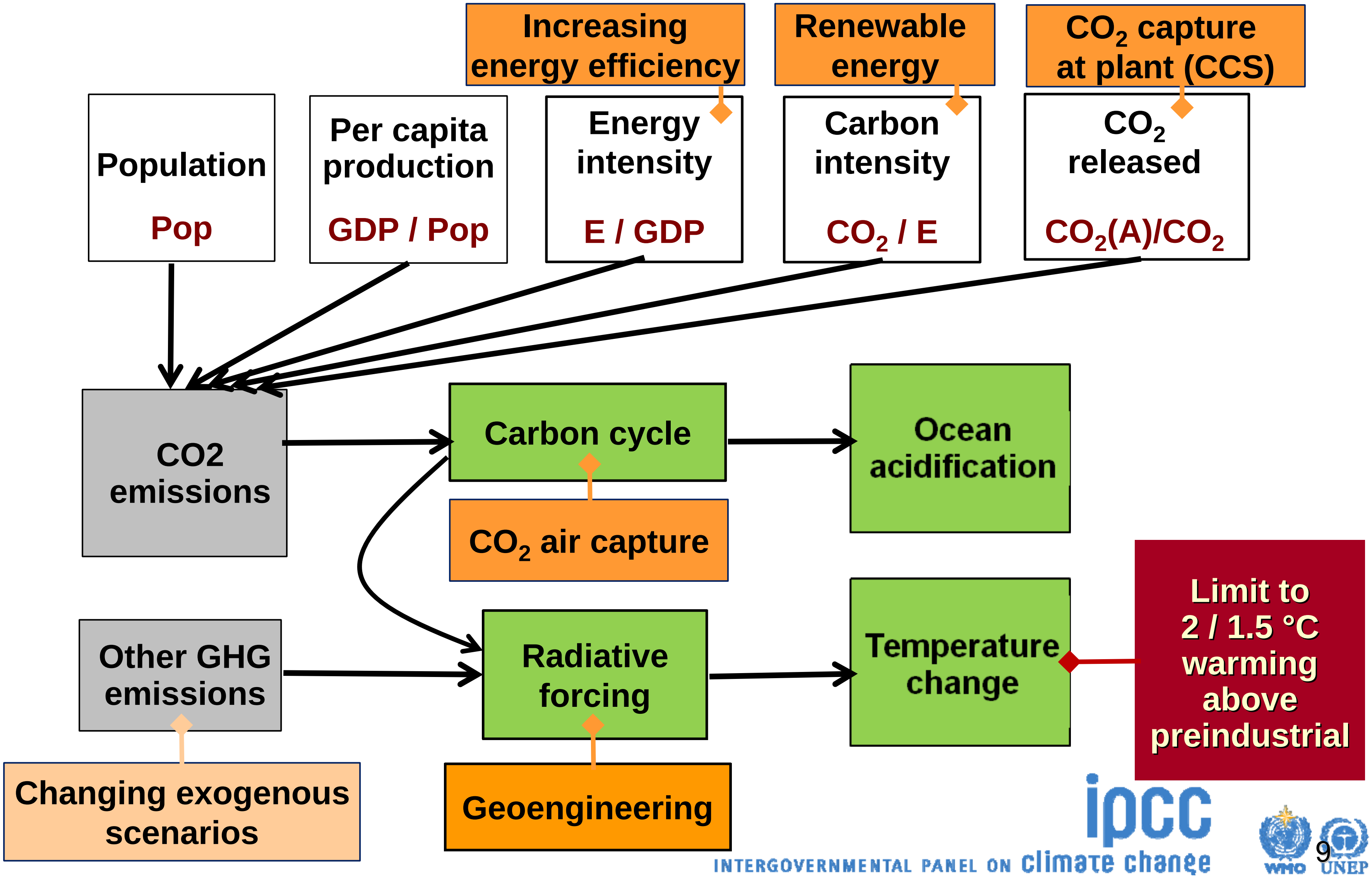
An emerging coalition between geo-engineers and environmentalists?



Increasing energy efficiency

Renewable energy

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Carbon cycle

Ocean acidification

CO_2 air capture

Other GHG emissions

Radiative forcing

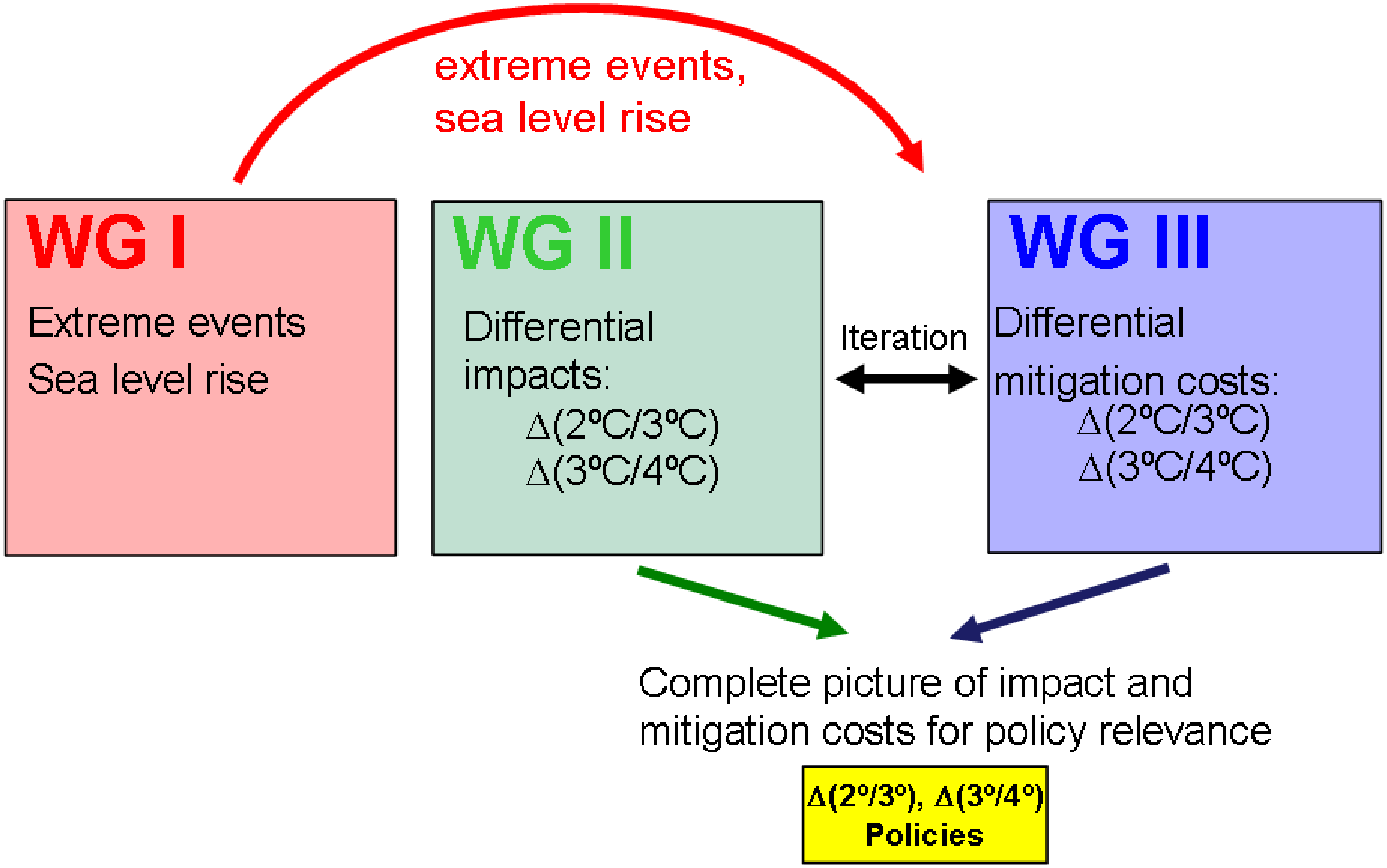
Temperature change

Limit to 2 / 1.5 °C warming above preindustrial

Changing exogenous scenarios

Geoengineering

Implications for the Scenario Process



extreme events,
sea level rise

WG I

Extreme events
Sea level rise

WG II

Differential impacts:
$\Delta(2°C/3°C)$
$\Delta(3°C/4°C)$

Iteration

WG III

Differential mitigation costs:
$\Delta(2°C/3°C)$
$\Delta(3°C/4°C)$

Complete picture of impact and mitigation costs for policy relevance

$\Delta(2°/3°)$, $\Delta(3°/4°)$
Policies

The Scientific Arena

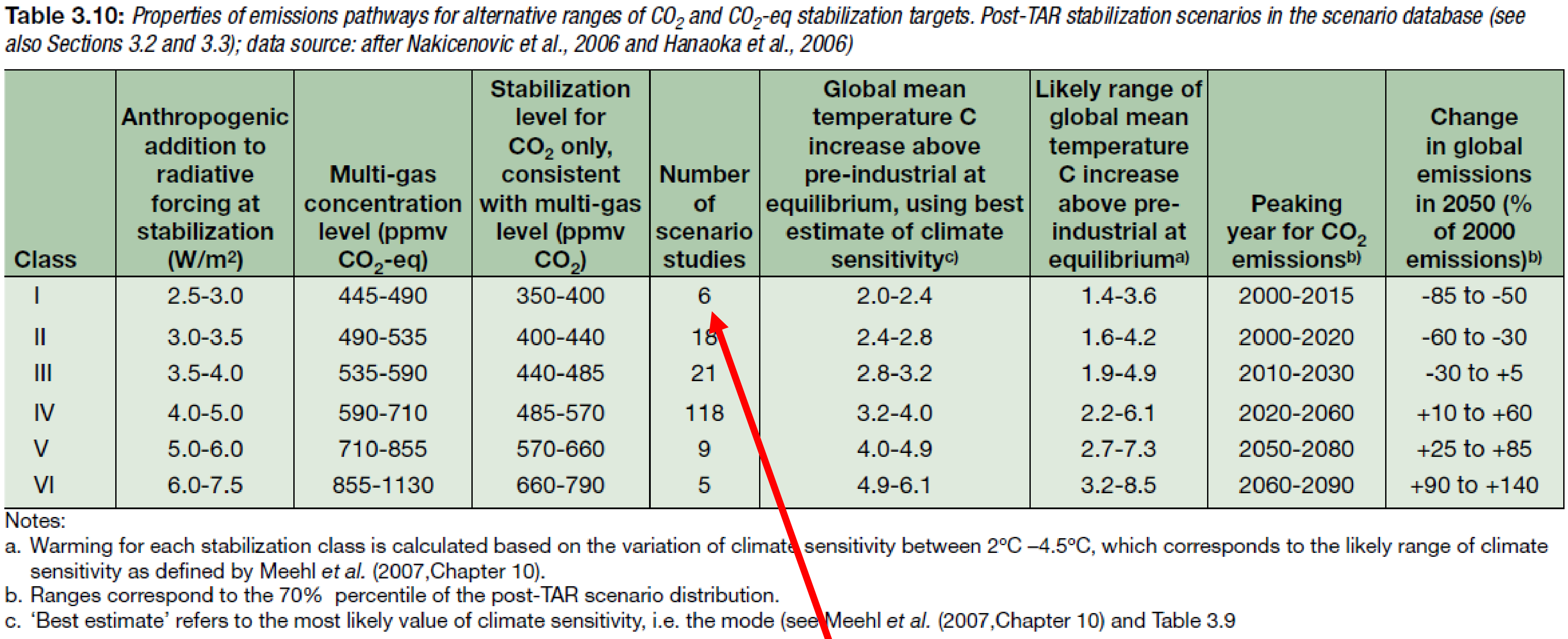


Table 3.10: *Properties of emissions pathways for alternative ranges of CO_2 and CO_2-eq stabilization targets. Post-TAR stabilization scenarios in the scenario database (see also Sections 3.2 and 3.3); data source: after Nakicenovic et al., 2006 and Hanaoka et al., 2006)*

Class	Anthropogenic addition to radiative forcing at stabilization (W/m²)	Multi-gas concentration level (ppmv CO_2-eq)	Stabilization level for CO_2 only, consistent with multi-gas level (ppmv CO_2)	Number of scenario studies	Global mean temperature C increase above pre-industrial at equilibrium, using best estimate of climate sensitivity[c)]	Likely range of global mean temperature C increase above pre-industrial at equilibrium[a)]	Peaking year for CO_2 emissions[b)]	Change in global emissions in 2050 (% of 2000 emissions)[b)]
I	2.5-3.0	445-490	350-400	6	2.0-2.4	1.4-3.6	2000-2015	-85 to -50
II	3.0-3.5	490-535	400-440	18	2.4-2.8	1.6-4.2	2000-2020	-60 to -30
III	3.5-4.0	535-590	440-485	21	2.8-3.2	1.9-4.9	2010-2030	-30 to +5
IV	4.0-5.0	590-710	485-570	118	3.2-4.0	2.2-6.1	2020-2060	+10 to +60
V	5.0-6.0	710-855	570-660	9	4.0-4.9	2.7-7.3	2050-2080	+25 to +85
VI	6.0-7.5	855-1130	660-790	5	4.9-6.1	3.2-8.5	2060-2090	+90 to +140

Notes:

a. Warming for each stabilization class is calculated based on the variation of climate sensitivity between 2°C –4.5°C, which corresponds to the likely range of climate sensitivity as defined by Meehl *et al.* (2007,Chapter 10).

b. Ranges correspond to the 70% percentile of the post-TAR scenario distribution.

c. 'Best estimate' refers to the most likely value of climate sensitivity, i.e. the mode (see Meehl *et al.* (2007,Chapter 10) and Table 3.9

Fisher et al. (2007), AR4

Only 6 scenarios from 3 models in the lowest category…

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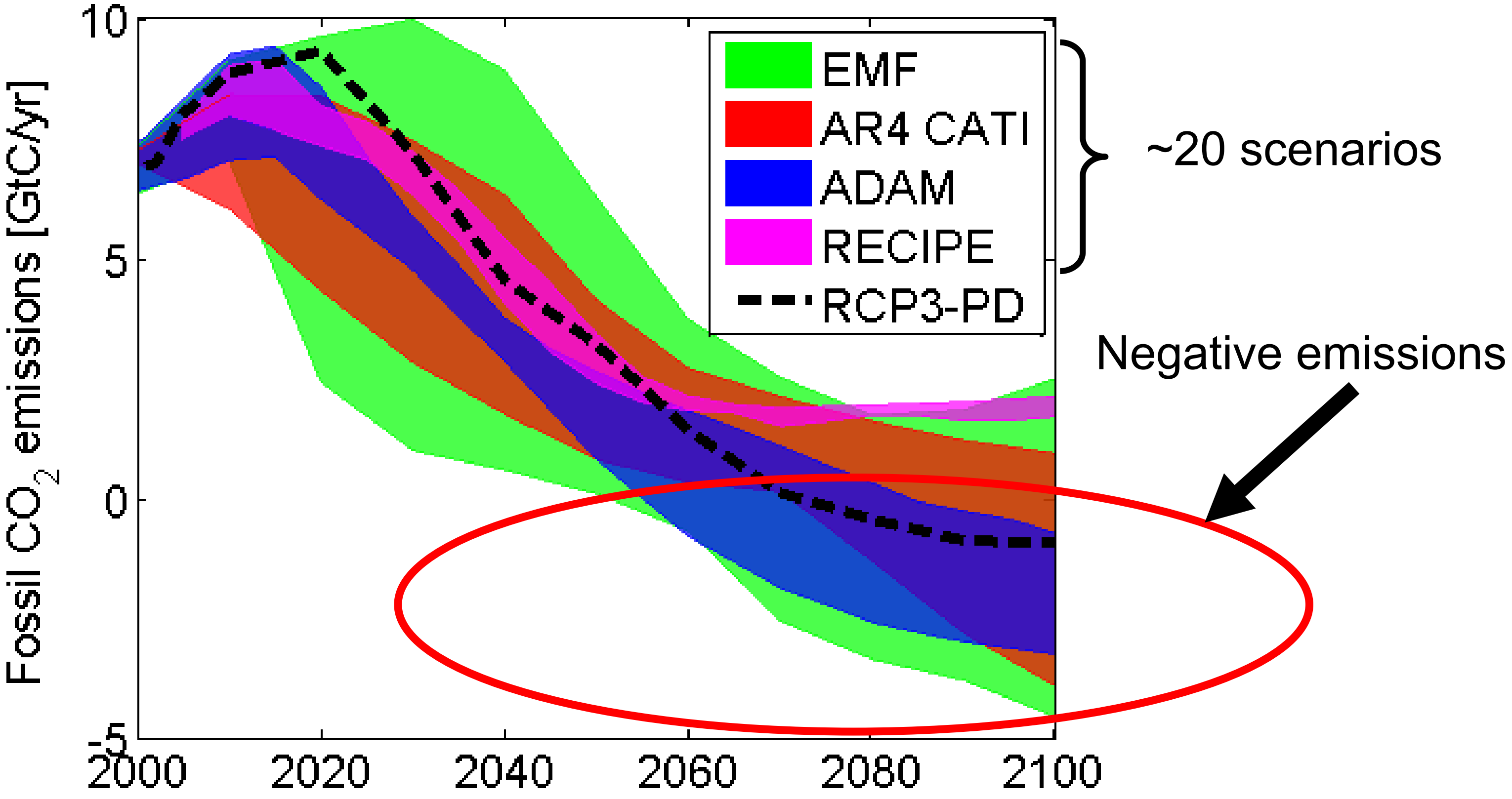
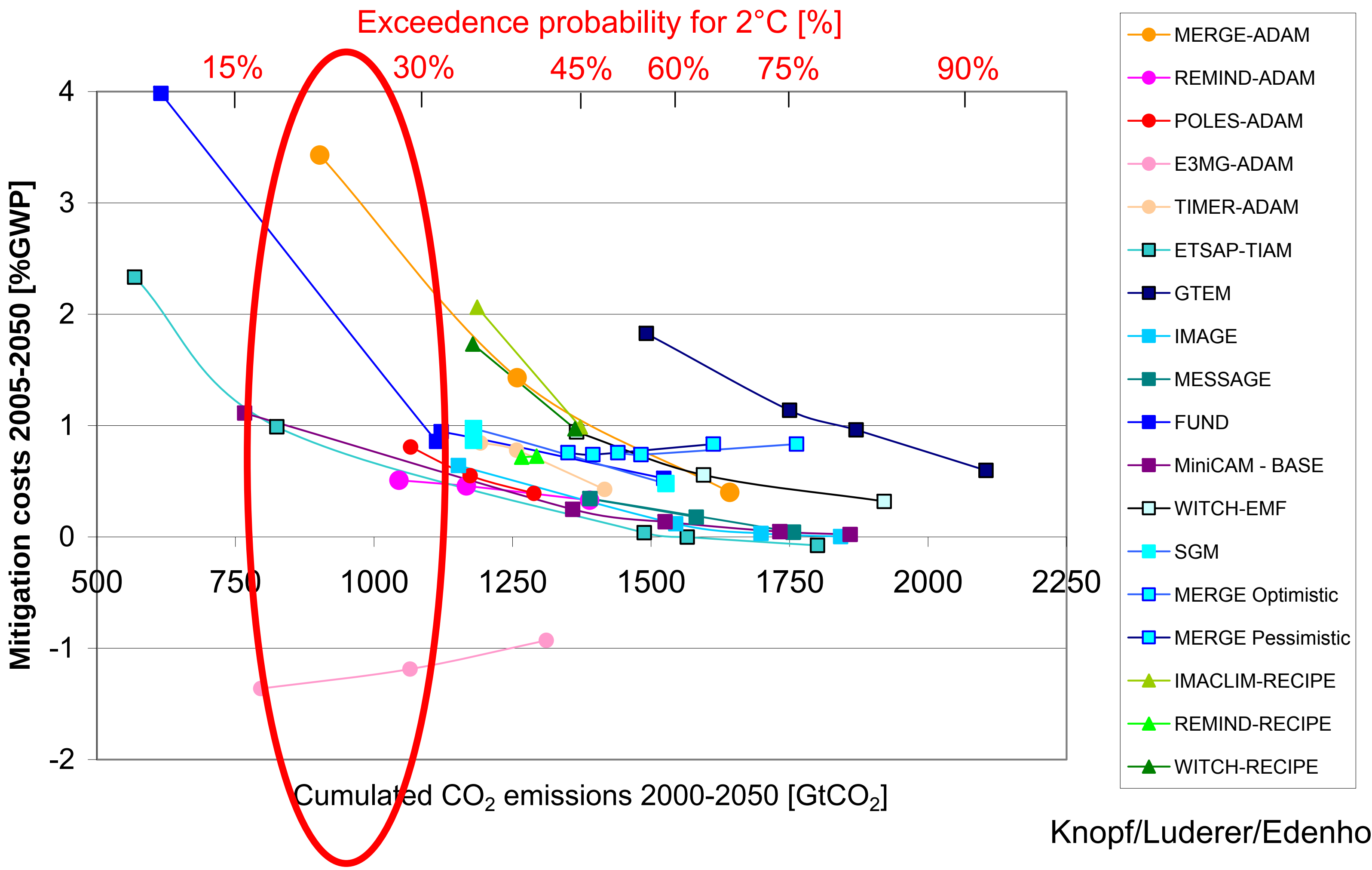
Low Mitigation Scenarios Beyond AR4

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



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 CO_2 removal (detached from sources)

2. Ability to (over)compensate past CO_2 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)

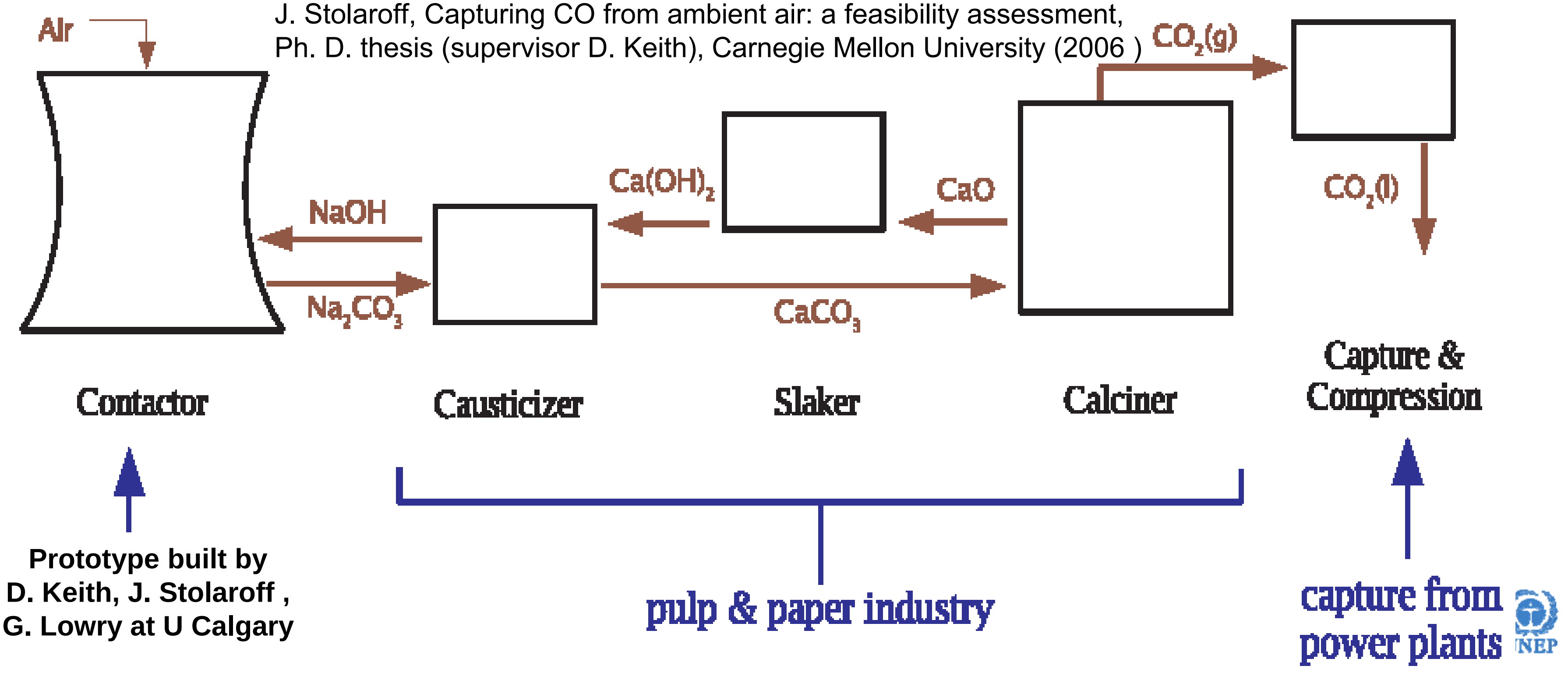
Direct Air Capture

Technically feasible

e.g. Lackner & Zeman (Columbia); Keith & Stolaroff (Calgary/CMU), Dubey (Los Alamos) , Baciocchi (Mazotti (Rome)

- energy for CO_2 compression < 10% hydrocarbon energy
- land area requirement small (> 40 ktC / km^2)
- process experience for simple designs, e.g. in pulp and paper industry

J. Stolaroff, Capturing CO from ambient air: a feasibility assessment,
Ph. D. thesis (supervisor D. Keith), Carnegie Mellon University (2006)



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

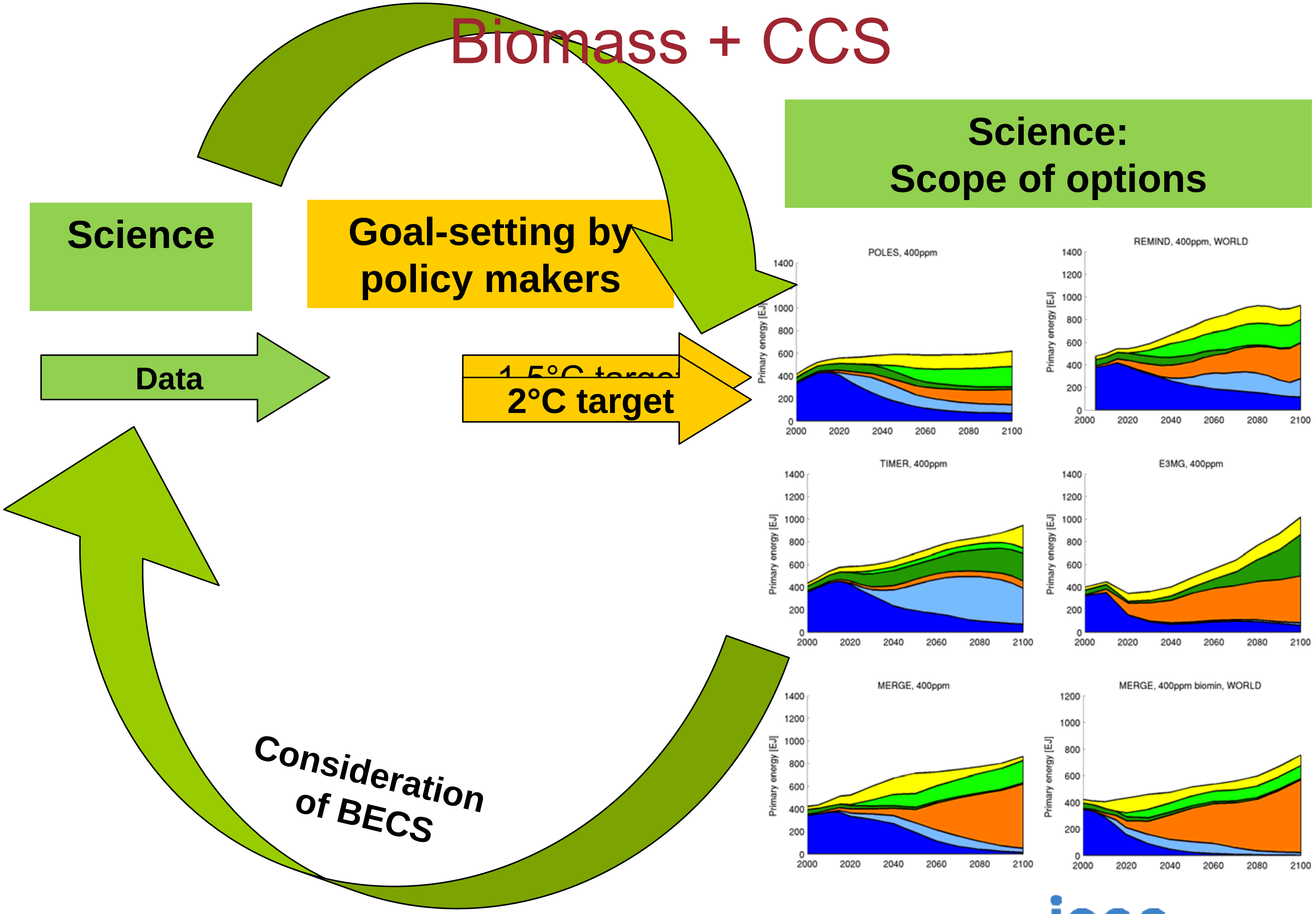
pulp & paper industry

capture from
power plants

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

Biomass + CCS



Science:
Scope of options

Science

Goal-setting by policy makers

Data

1.5°C target

2°C target

Consideration of BECS

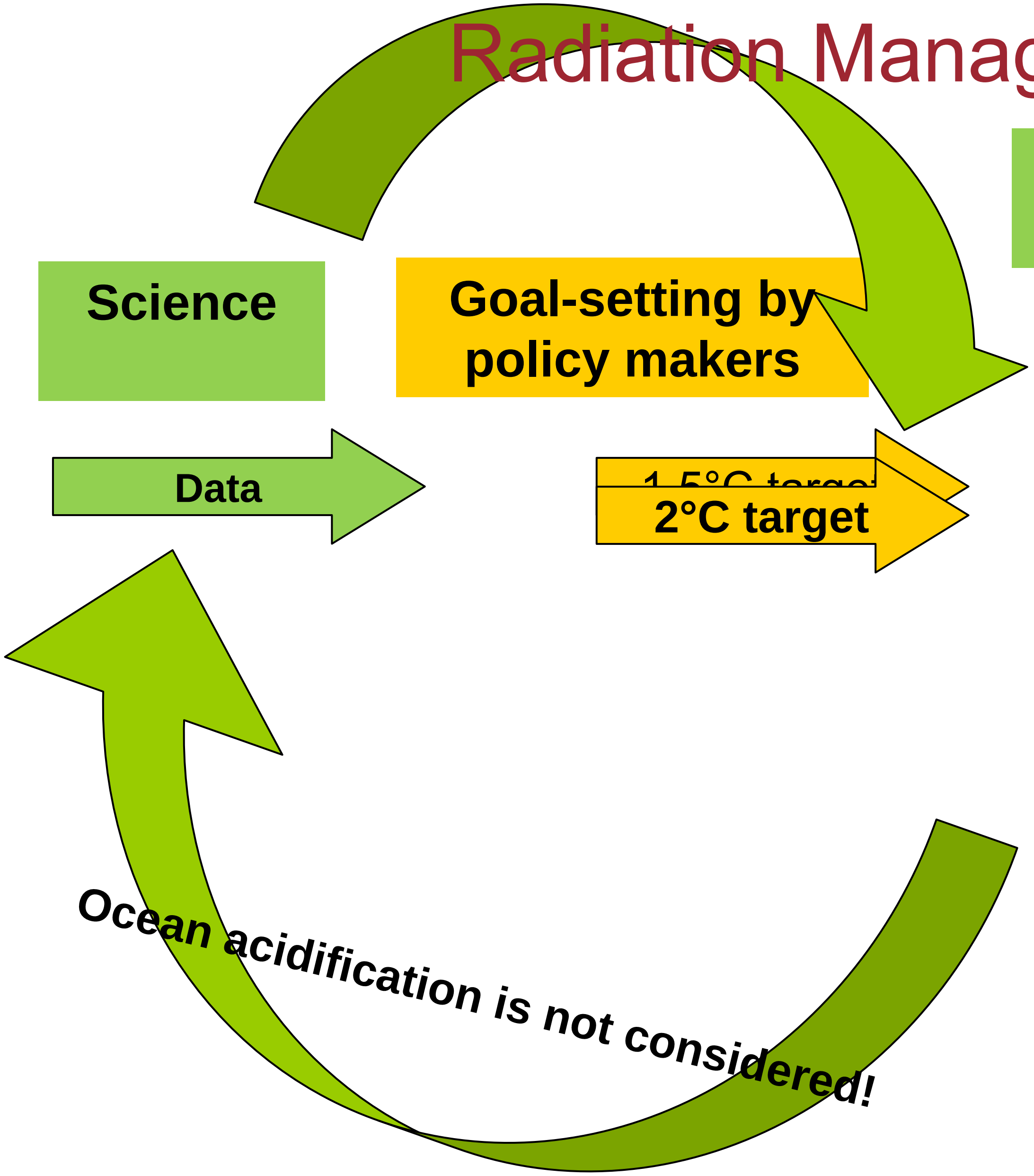
Biomass + CCS

- 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

Radiation Management



Science

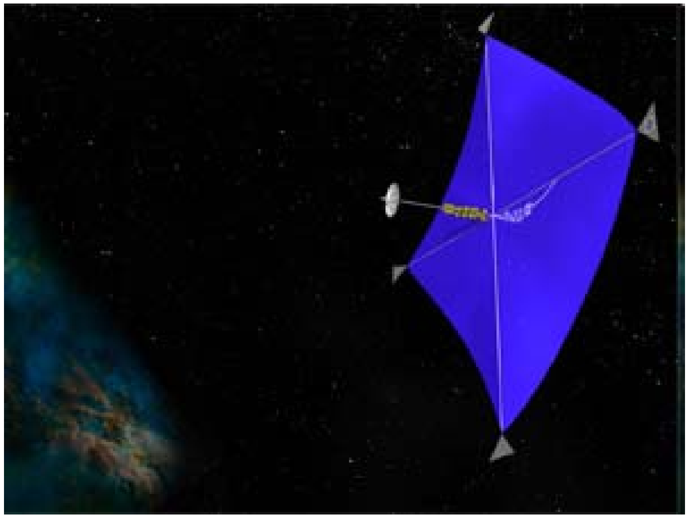
Data

Goal-setting by policy makers

1.5°C target

2°C target

Science: Scope of options



Ocean acidification is not considered!

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?

Table of Content

- 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(·)

    $$Q(x_1, \ldots, x_N) = \ldots$$
  - Unit costs C(·)

    $$C(x_i) = c \cdot x_i$$
- Here, we choose

  $$\alpha = 6, \qquad c = 4$$

Player 2

Player 1

	X2 = 1	*X2 = 0*
X1 = 1	$\pi_2(1,1)$ $\pi_1(1,1)$	$\pi_2(1,0)$ $\pi_1(1,0)$
X1 = 0	$\pi_2(0,1)$ $\pi_1(0,1)$	$\pi_2(0,0)$ $\pi_1(0,0)$

Mitigation as a Prisoner‘s Dilemma

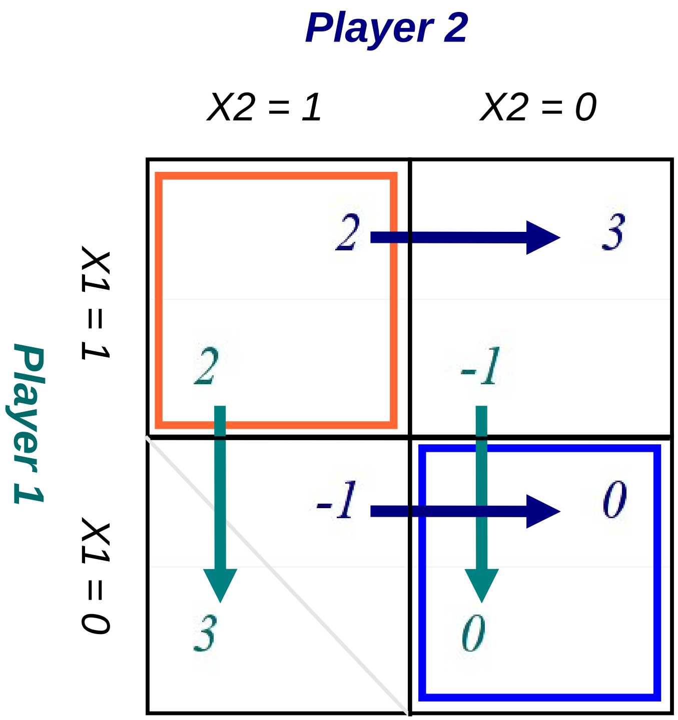
$$\pi_i = \alpha \cdot Q(x_1, x_2) - c \cdot x_i \quad \textit{with} \quad \alpha = 6, \qquad c = 4$$

- “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?

$$\pi_i = \alpha \cdot Q(x_1, x_2) - c \cdot x_i \quad \textit{with} \quad \alpha = 6, \qquad c = 4$$

- “Best Shot”

$$Q(\cdot) = \max\{x_1, \ldots, x_n\}$$

		Player 2	
		X2 = 1	*X2 = 0*
Player 1	*X1 = 1*	*2* *2*	*6* *2*
	X1 = 0	*2* *6*	*0* *0*

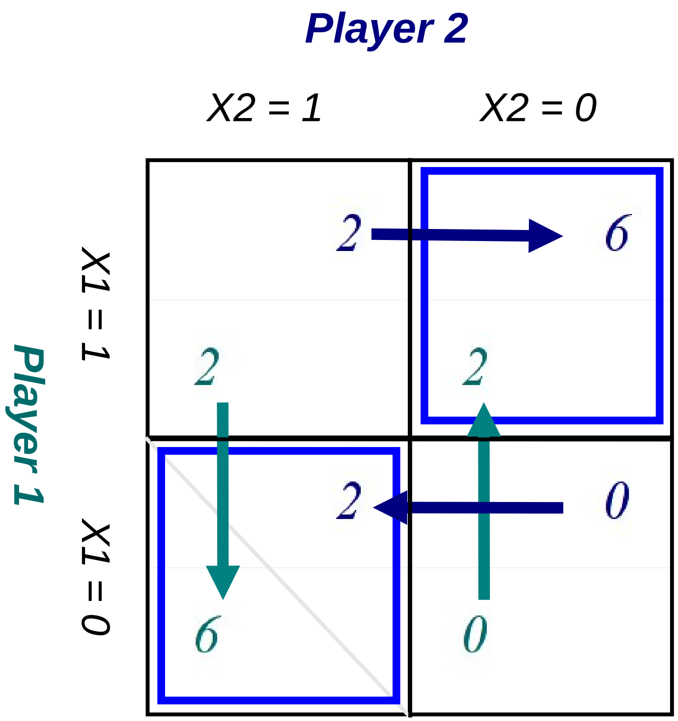
Could radiation management solve the cooperation problem?

$$\pi_i = \alpha \cdot Q(x_1, x_2) - c \cdot x_i \quad \textit{with} \quad \alpha = 6, \qquad c = 4$$

- “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!

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