Climate Targets and Cost Effective Climate Stabilization Pathways (II)

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How much mitigation is desirable?
Cost Benefit Analysis: The standard tool of environmental economics

Present-day mitigation costs

Future avoided damages

Conceptual Difficulties

- Impacts poorly known
  - Often poor natural science/engineering knowledge (at least today)
  - Need for valuation of goods
- Need to weigh
  - Present mitigation costs … against …
  - Future avoided damages

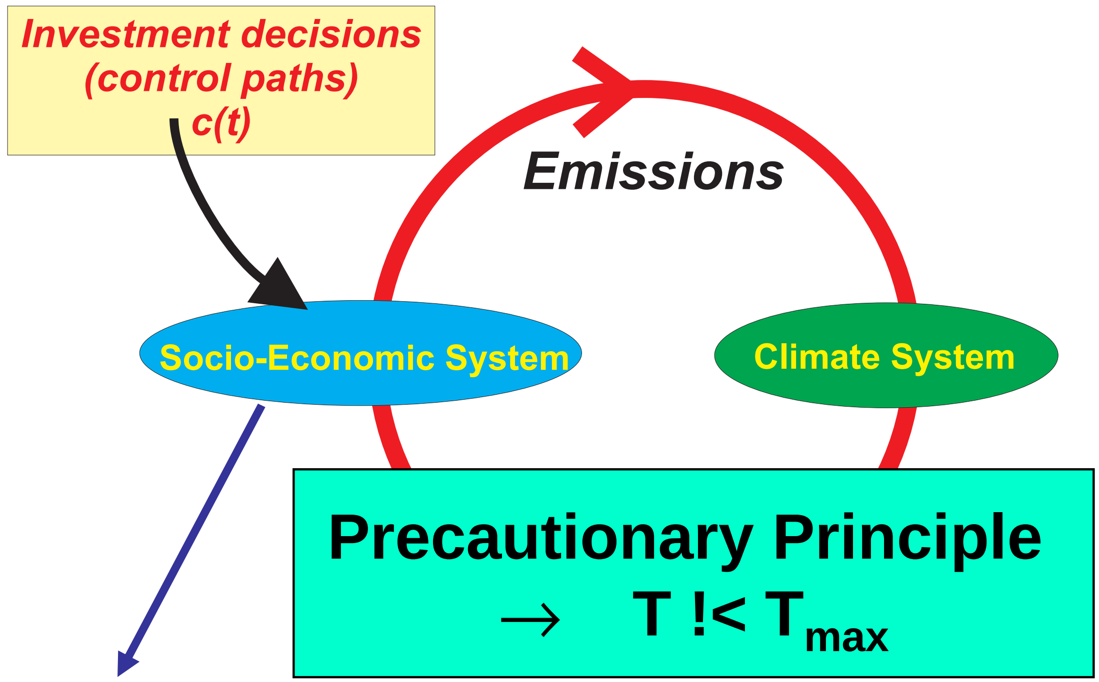
- An easier & better-posed alternative? …

When to Invest How Much into which Energy Technology?

Phrasing as a Control Problem

Investments in

- ***Renewables***
- ***Efficiency***
- ***Fossil Fuels***
- ***CCS***



$$\text{Max!}_{(c(t_0),\ldots,c(\infty))}\ \text{Welfare} := \int_{t_0}^{\infty} dt\ \boxed{\text{Utility'}}(t)[(c(t_0),\ldots,c(t))]\ e^{-\rho t}$$

$$\text{subject to} \quad \forall_t\ T(t)[(c(t_0),\ldots,c(t))] < T_{\max}$$

‘Cost-Effectiveness-Mode’

This ‘truncated decision problem’ is informative…

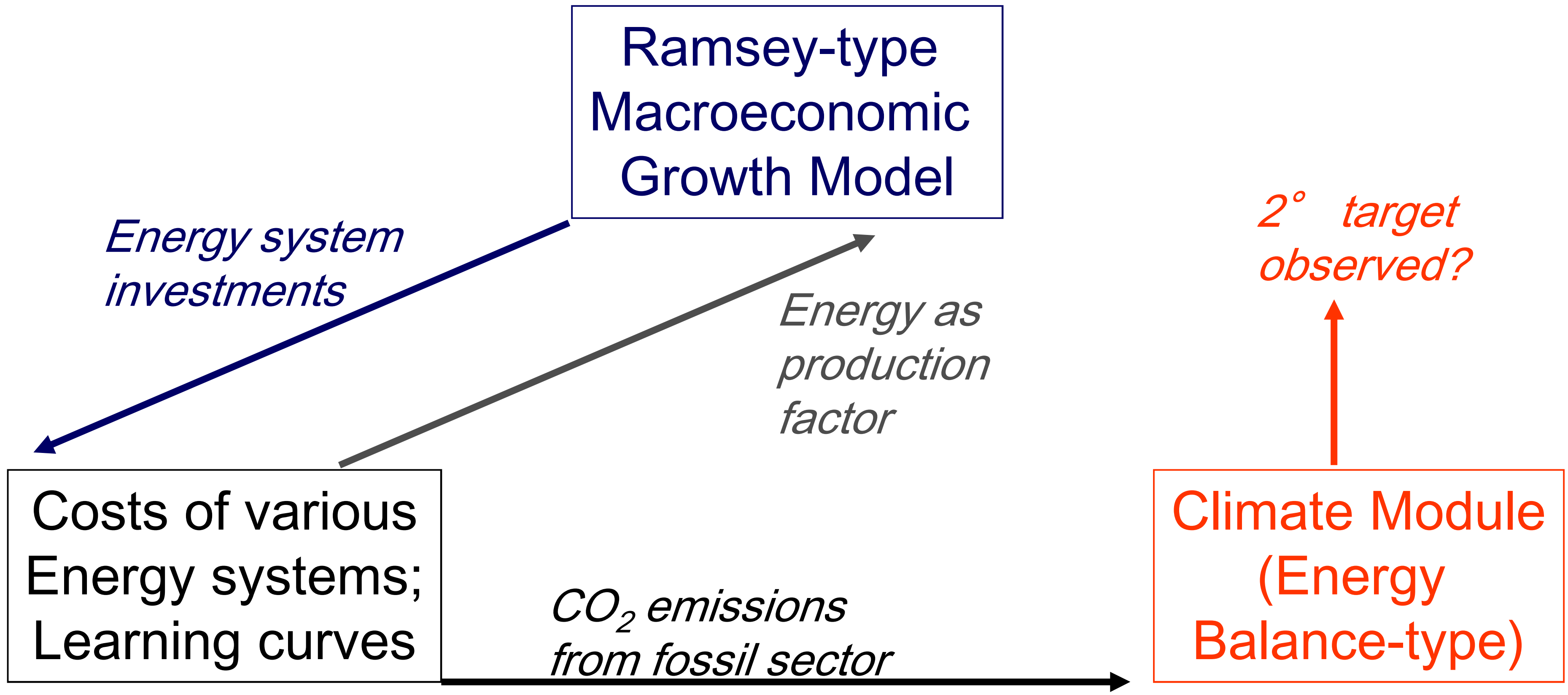
..if costs of the environmental target are found to be ‘low’

***and* the target satisfies ‘the environmentalist’.**

Our Research Question

- **When** to invest **how much** into **what energy** technology, given the 2° C (X° -)target?
- Options:
  - Renewable sources
  - Energy efficiency
  - Carbon capture & sequestration (CCS)
  - Nuclear
- ⇒ coupled economy – climate modules.

Costs of Climate Targets?
Our Model Setup



Edenhofer et al. (MIND / ReMIND; 2005-2012)

The simplest Climate Model

Control Variable

$$\dot{F} = E \quad (1)$$

$$\dot{C} = \beta E + \mathrm{B} F - \sigma C \quad (2)$$

$$\dot{T} = \mu \ln(c) - \alpha T \quad \text{with } c = \frac{C + C_{pi}}{C_{pi}} \quad (3)$$

Variable used for guardrail in CostEffectivenessAn.

Variables	
E	Anthropogenic CO_2 emissions [GtC a^{-1}]
F	Cumulative anthrop. CO_2 emissions [GtC]
C	Atmospheric CO_2 anomaly [ppmv]
T	Global mean temperature anomaly [^oC]

Initial conditions (year 1995, pi = preindustrial)

Intertemporal Optimization as a key application of Utilitarism

- One application of ‘Static Welfare:= average of individuals’ utilities’

$$\text{Max! Welfare} := \int_{t_0}^{\infty} dt\; U(t)\; \mathrm{e}^{-\rho(t-t_0)}$$

t_0 ← ‘now’

- ρ := ‘pure rate of time preference’
- Battle among economists: is ρ a normative or a positive (i.e. descriptive) parameter?

Why ‘exp’?

A highly desirable Property of this Welfare Functional

$$\text{Max! Welfare} := \int_{t_0}^{\infty} dt\ U(t)\ \mathrm{e}^{-\rho(t-t_0)}$$

t_0 ← ‘now’

This prescription is ‘time-consistent’:

Let {c*(t)} a control path that optimizes above welfare W ($[t_0,\infty[$).

Let $t_0<t_1$.

Then {c*} also optimizes W($[t_1,\infty[$).

Anticipated time-inconsistency: Odysseus & the Sirens

http://vampirella91.de.tl/Drachen-und-Sirenen.htm

This means:

- If boundary conditions stay the same, the decision-maker does not need to change her or his plans over time.
- An (in my view) necessary property of any normative decision rule.
- T C Koopmans showed that the discounting function must be an exponential one for time-consistency.

2 Interpretations of Technological Progress Leading to Cost Reduction

	Endogenous Technological Change	**Exogenous Technological Change**
Definition	Cost reduction primarily a function of **total installed capacity**	Cost reduction primarily a function of **time** (spill-over effects from overall technol. development)
Consequence for climate policy	Investment into new technologies can accelerate their cost reduction → early deployment?	Investment into new technologies does *not* accelerate their cost reduction → later deployment?

2 Interpretations of Technological Progress Leading to Cost Reduction

The following studies: ↓

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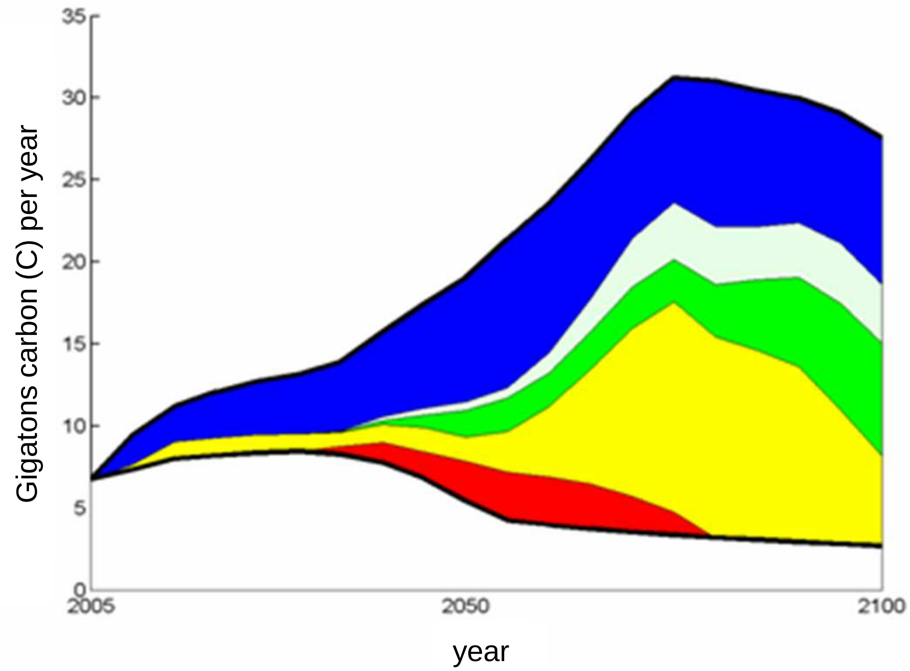
Bridging the Mitigation Gap



From REMIND-G (0D-Model)

Energy-induced emissions

nuclear
renewables
biomass + CCS
fossil + CCS
efficiency

Bruckner, Edenhofer, Held et al., 2009

Coal/Oil/Nat.Gas cheap, pure time preference rate 1%

Generically, a mix of energy options is economically optimal.

Costs of Mitigation?

IPCC AR5 WGIII (April 2014) assessed ~1000 energy-economic scenarios, published since AR4 (2007)

IPCC

- Intergovernmental panel on climate change

- Triggered by UN & WMO

- “Assessment reports” delivered in 1990, 1995, 2001, 2007, 2014 (hence in 2014: “AR5”)

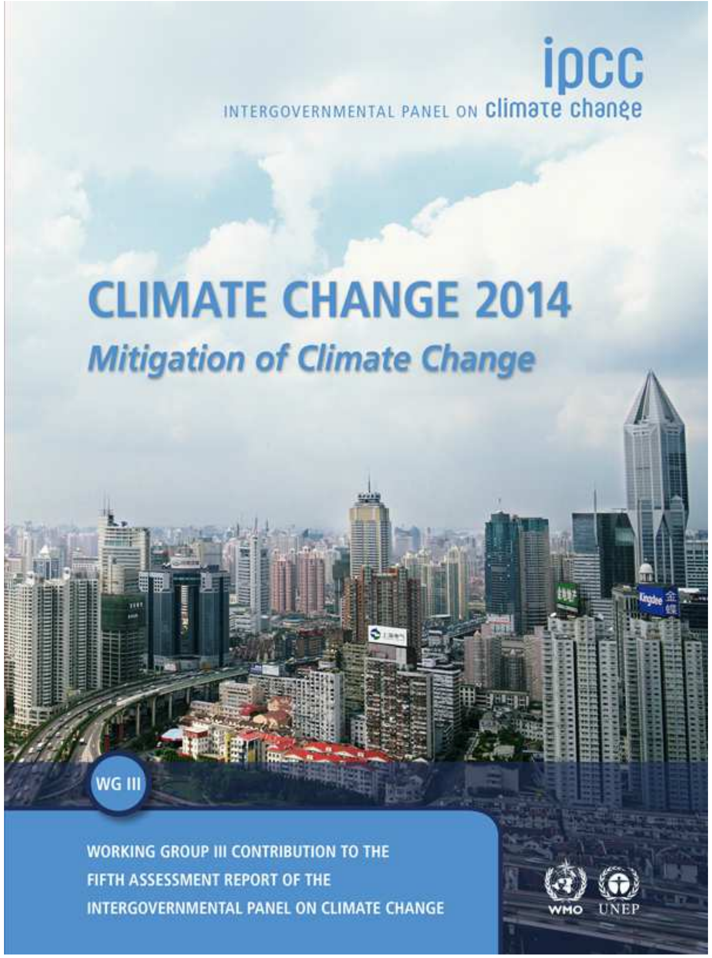
- 3 working groups
  I. Physical basis
  II. Global warming impacts & adaptation
  III. Mitigation

IPCC reports are the result of extensive work of many scientists from around the world.

Report by WGIII

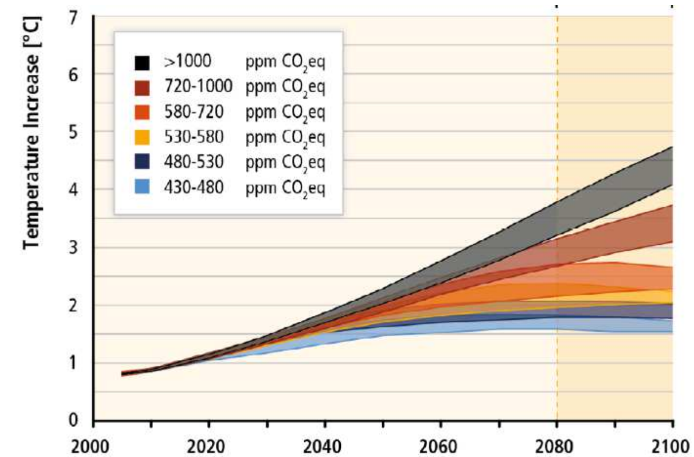
1 Summary for Policymakers
(jointly by experts & governments)
1 Technical Summary

16 Chapters
(incl. Executive Summaries)
235 Authors
900 Reviewers
More than **2000** pages
Close to **10,000** references
More than **38,000** comments



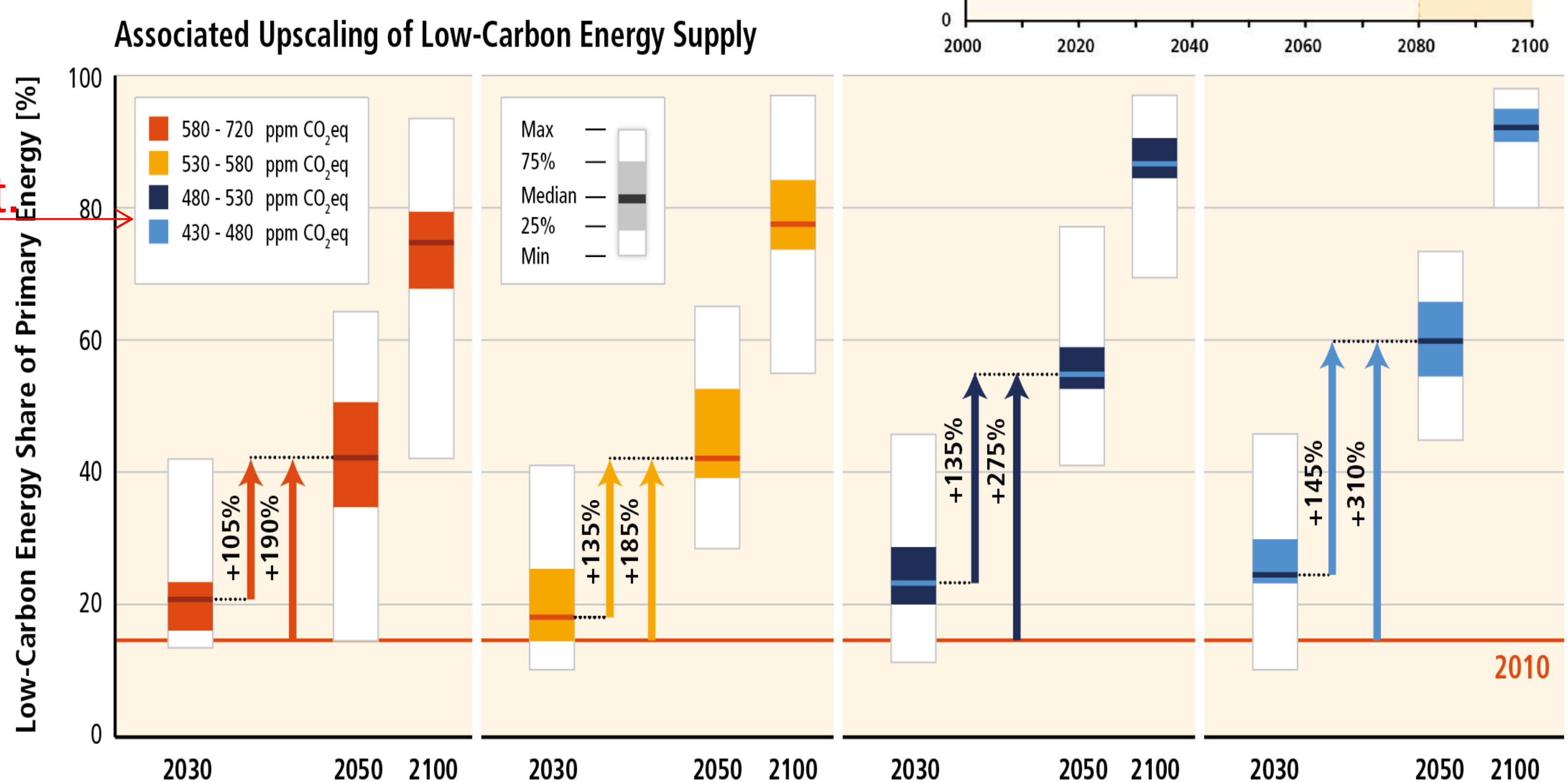
-> 4 Levels of aggregation

Mitigation requires major technological changes including the upscaling of low- and zero carbon energy.



IPCC AR5 WGIII, Figure SPM.4.

2° compat.



Economic Welfare Effects of 450ppmeq (~2° C) Target?

- Economic reference case:

  Scenario without climate damages and without climate policy
- This is characterized by global economic growth of 1,6 - 3 % / year.

- 2°-oriented scenarios compatible with continued global economic growth.
- Annual growth rate reduced by 0.06 %- points .

- Hereby avoided warming-induced net damages not yet included.

- *(After IPCC AR5 WGIII SPM)*

- 2° target '~insurance premium against unpredictable warming damages'

Estimates for mitigation costs vary widely.

- Reaching 450ppm CO_2eq (~2° target) entails consumption losses of
  - 1.7% (1%-4%) by 2030,
  - 3.4% (2% to 6%) by 2050 and
  - 4.8% (3%-11%) by 2100

  relative to baseline (which grows between 300% to 900% over the course of the century).

- **This is equivalent to a reduction in consumption growth over the 21st century by about**
  - **0.06 (0.04-0.14) percentage points a year**
  - **(relative to annualized consumption growth that is between 1.6% and 3% per year).**

IPCC AR5 WGIII, SPM, p.17

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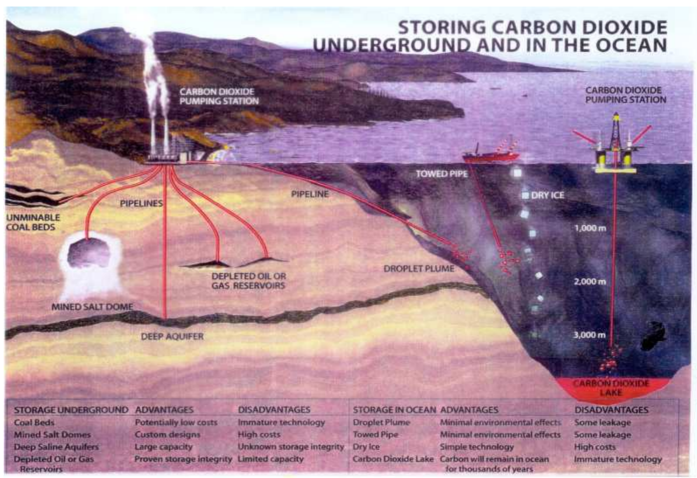
How important are individual technologies?

What additional costs would occur if a certain technology were excluded from the portfolio?



CCS

(CO_2-Capture & Sequestration / Storage)

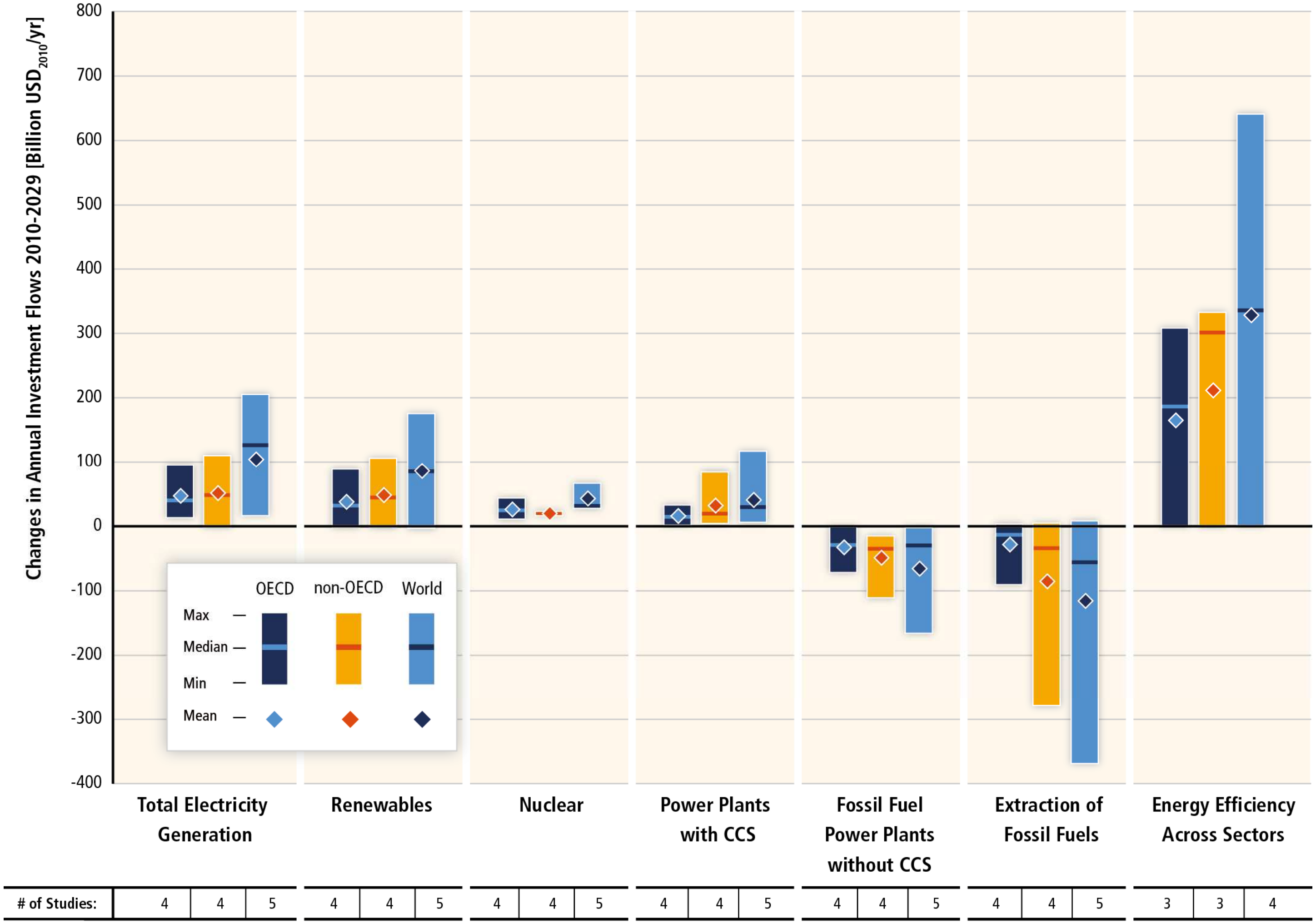
+50% to +250%

Fission

+5% to +15%

(Read from Fig TS.13, IPCC AR5 WGIII)

Substantial reductions in emissions would require large changes in investment patterns.



stabilize concentrations within the range of approximately 430–530 ppm CO2eq by 2100

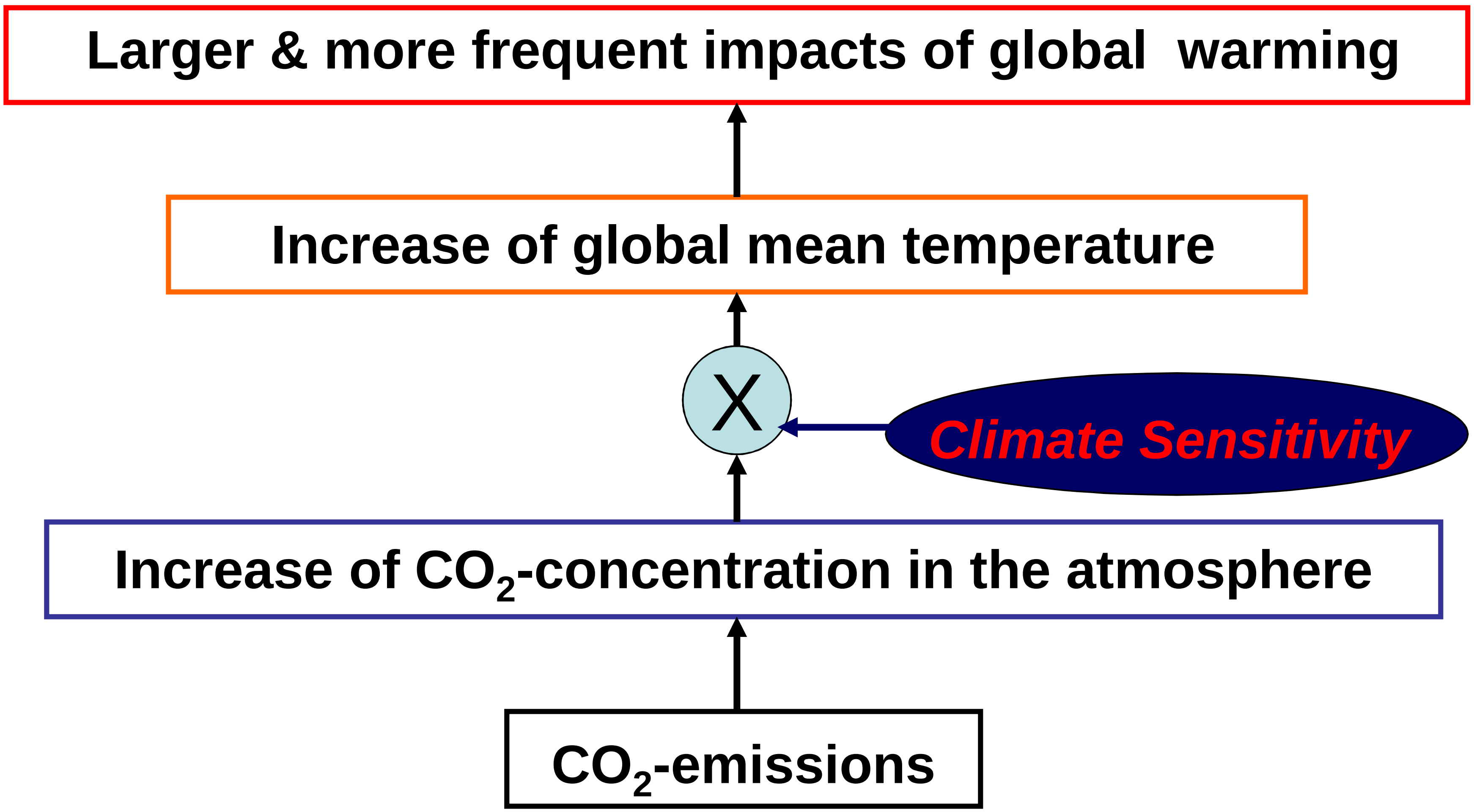
IPCC AR5 WGIII, Figure SPM.9.

Hedging Strategy needed in view of 'Irreversibility Effect under Uncertainty'

- Our actions may have irreversible effects:
  - Investing too early in a specific energy technology or adaptation measures may lead to stranded investments.
  - Waiting too long on mitigation may trigger irreversible climate system or ecological effects.

$\rightarrow$ Again an application for optimisation, if uncertainty is reflected in the welfare function.

Key Factor Climate Sensitivity



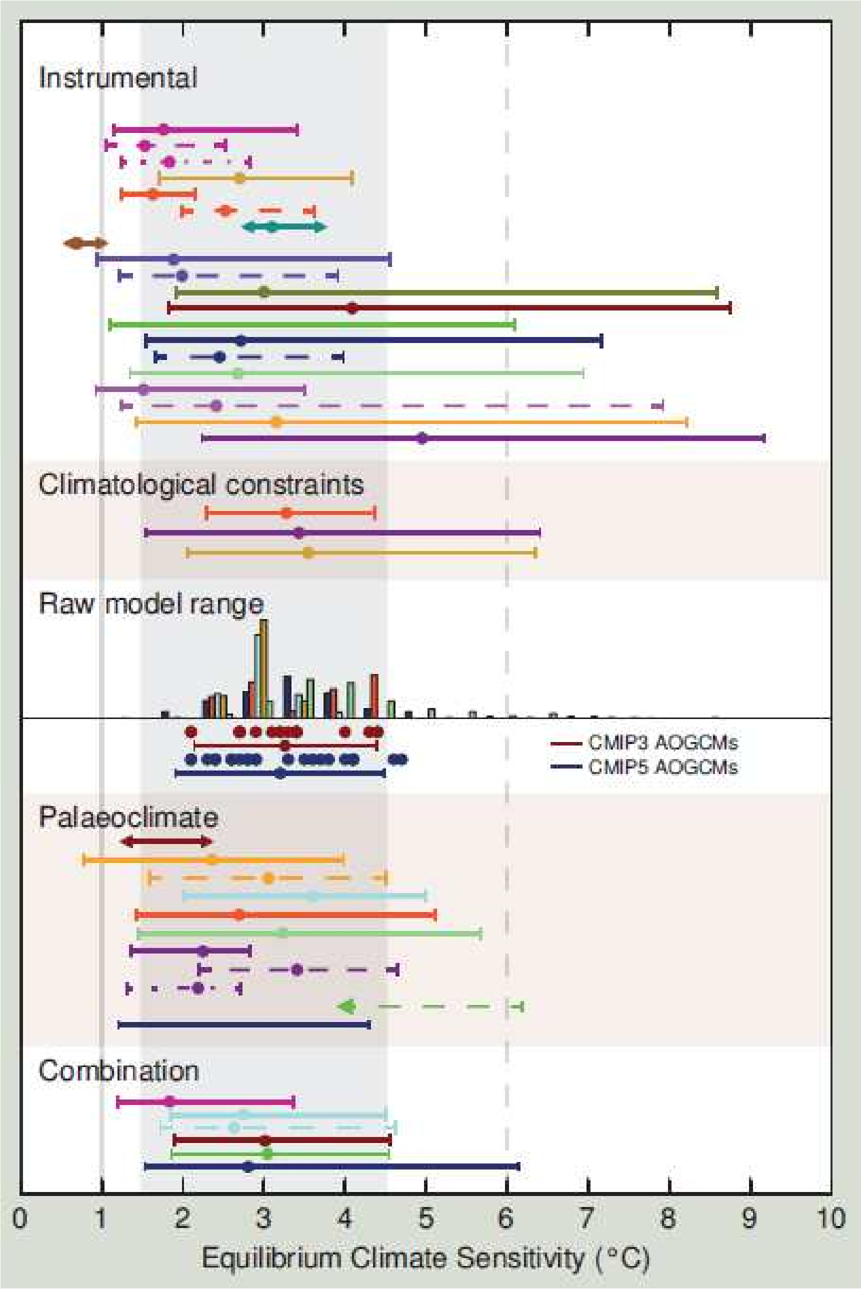
Definition of Climate Sensitivity

- CS:= Change in global mean surface temperature for doubling pre-industrial CO_2 concentration, i.e.

- T(560 ppm CO_2) – T(280 ppm CO_2)

- *Convenient climate system surrogate: Uncertainty in CS explains > 50% of uncertainty in global warming projections*

Estimates of Climate Sensitivity



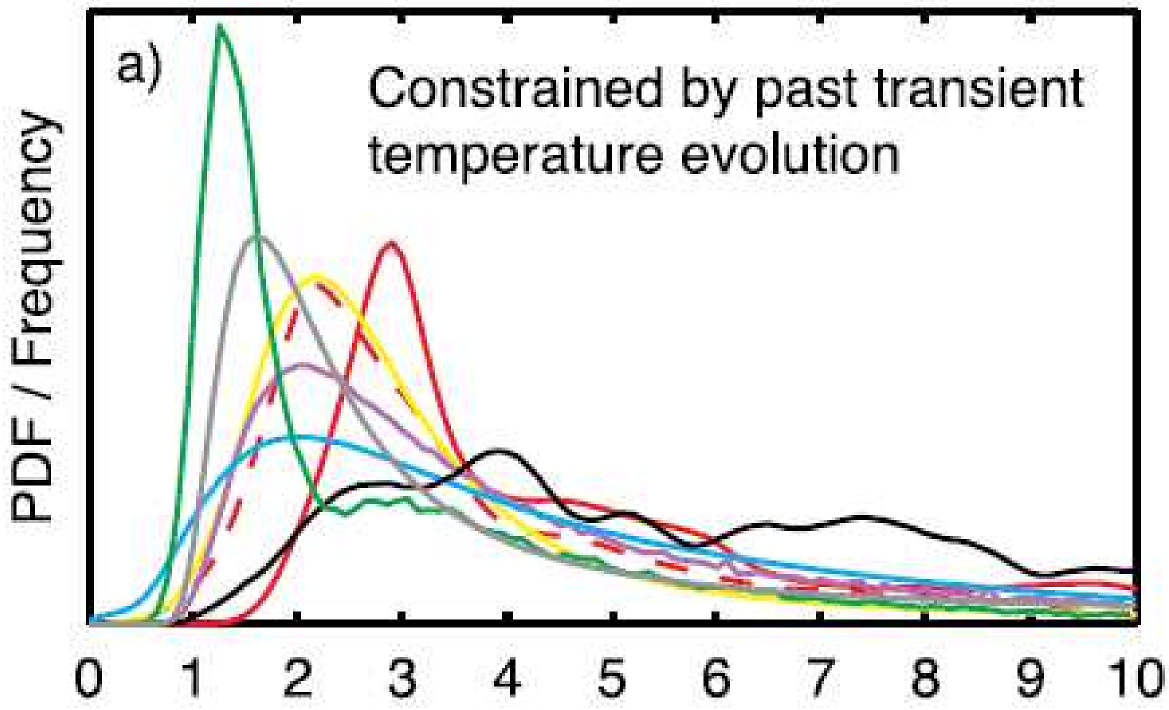
IPCC AR5 TS (2013)

None of the reconstruction methods opens room for '0' climate sensitivity.

TFE.6, Figure 1 | Probability density functions, distributions and ranges for equilibrium climate sensitivity, based on Figure 10.20b plus climatological constraints shown in IPCC AR4 (Box AR4 10.2 Figure 1), and results from CMIP5 (Table 9.5). The grey shaded range marks the *likely* 1.5°C to 4.5°C range, grey solid line the *extremely unlikely* less than 1°C, the grey dashed line the *very unlikely* greater than 6°C. See Figure 10.20b and Chapter 10 Supplementary Material for full caption and details. {Box 12.2, Figure 1}

- Uncertainty in temperature response is on the same order of magnitude than the very effect.

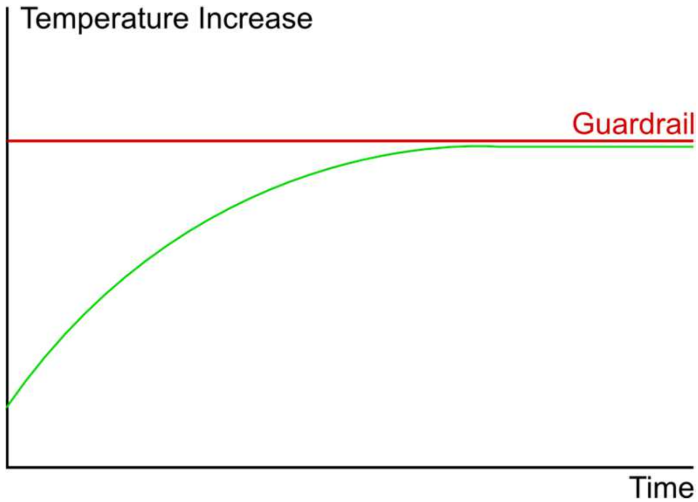
- Hence, uncertainty should become part of the decision-calculus.



IPCC AR4 WGI

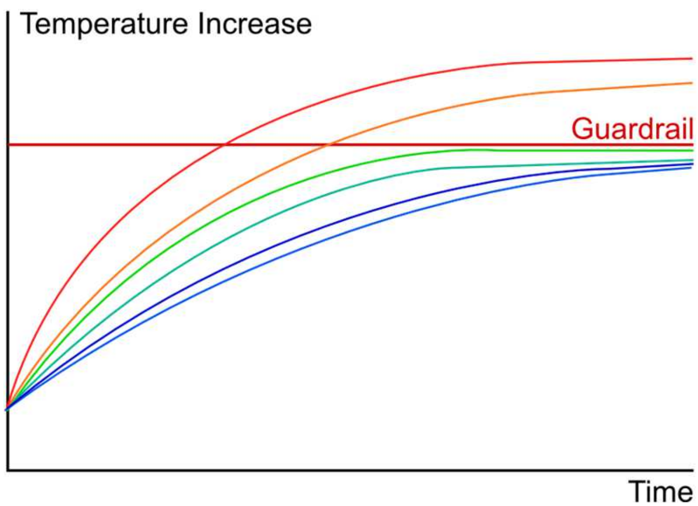
We can always find CS-values such that a temperature limit is overshot.

As Climate Sensitivity could be arbitrarily large: ⇒ The Need for Probabilistic Guardrail 'Chance Constrained Programming' (CCP)



<u>Deterministic Guardrail</u>

- Single Investment Strategy
- Single Temperature Profile keeping the Guardrail



<u>Probabilistic Guardrail</u>

- Single Investment Strategy
- Multiple Temperature Profiles due to Uncertainties
- p% keep the Guardrail
- (1-p)% may exceed the Guardrail

den Elzen and van Vuuren 2007, H. Held et al. 2009

Need decades earlier investments into low-C technologies, if we request a chance of compliance of at least 2/3.

(Held et al., 2009)

However when also anticipating future learning about climate response, CCP displays conceptual problems….

1st Problem with CCP:
Risk of Infeasible Solution

- In order to prepare for high-end cases after learning, the allowed cumulative amount of emissions before learning gets too restricted
- -> *infeasible solution!*
  - Because an upper bound for allowed Cumulative Emissions scales with **$(2^{T / CS} - 1)$** in 1st order as a function of Asymptotic Temperature T

    (Kriegler&Bruckner, Clim. Change, 2004)

2nd Problem with CCP:

By construction, a damage function is missing ,

- hence Expected Value of Information could be negative

The Need for Cost Risk Analysis

- Then we may need a hybrid approach derived from both

  cost effectiveness / cost benefit analysis

- We developed such a tool (price in probability of overshoot).
- ‘Cost Risk Analysis’
- Calibrate it at the 2° target.

- Derive that expected economic gain from perfect climate information is up to

  hundreds of billions of €/year under 2° target. (Neubersch, Held, Otto, subm. *Climatic Change*)

Problems to tackle for a successful mitigation policy (if wanted)

- Disentanglement of causes & effects across space & time
  - Mainly developing nations suffer from global warming
  - Benefits of mitigation delayed by 50 years.

- ‘Just’ distribution of emission budget? What is a ‘just’ world order?

- Free-rider problem

- Devaluation of fossil resources -> lobby pressure

- Potential for yet unknown side effects (solar thermodyn. more robust than wind, Miller et al.; CCS; fission)

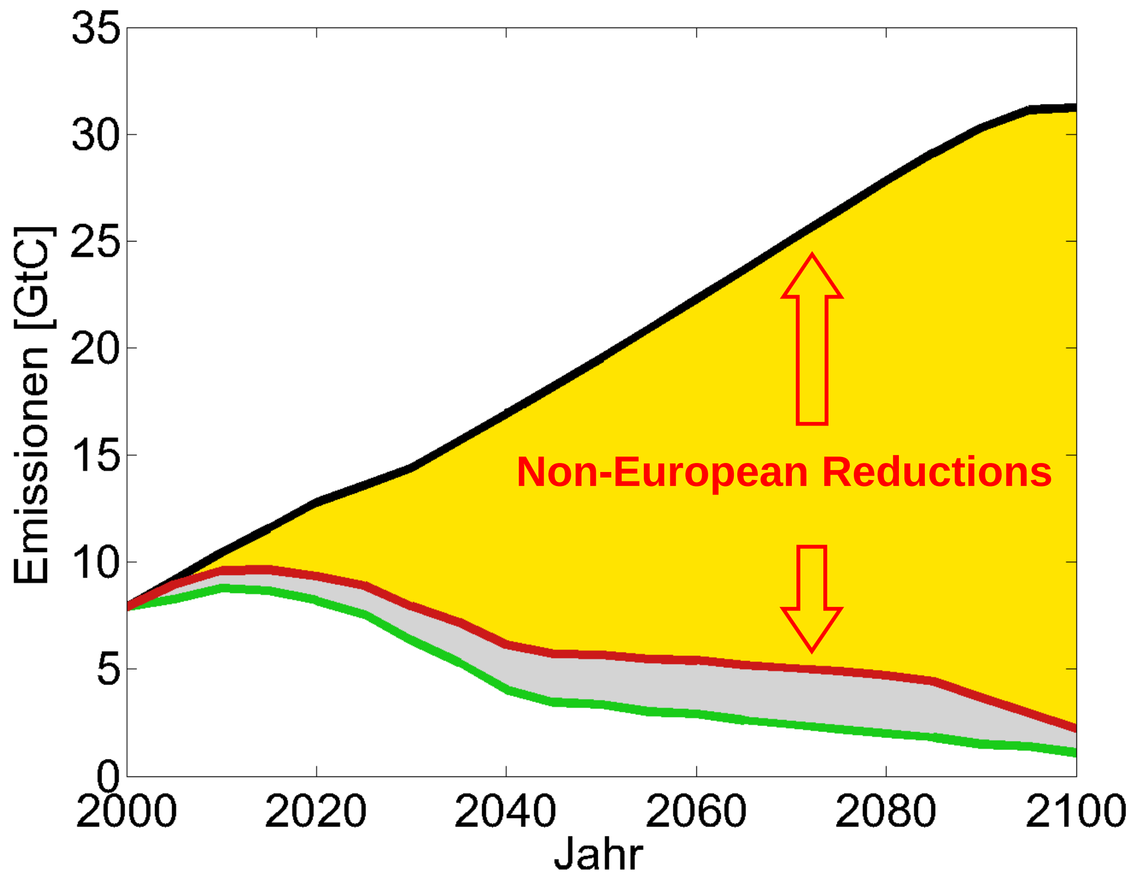
- Information asymmetries in society & intra-national negotiations

- Climate problem hard to attach to by our senses – ‘very abstract’

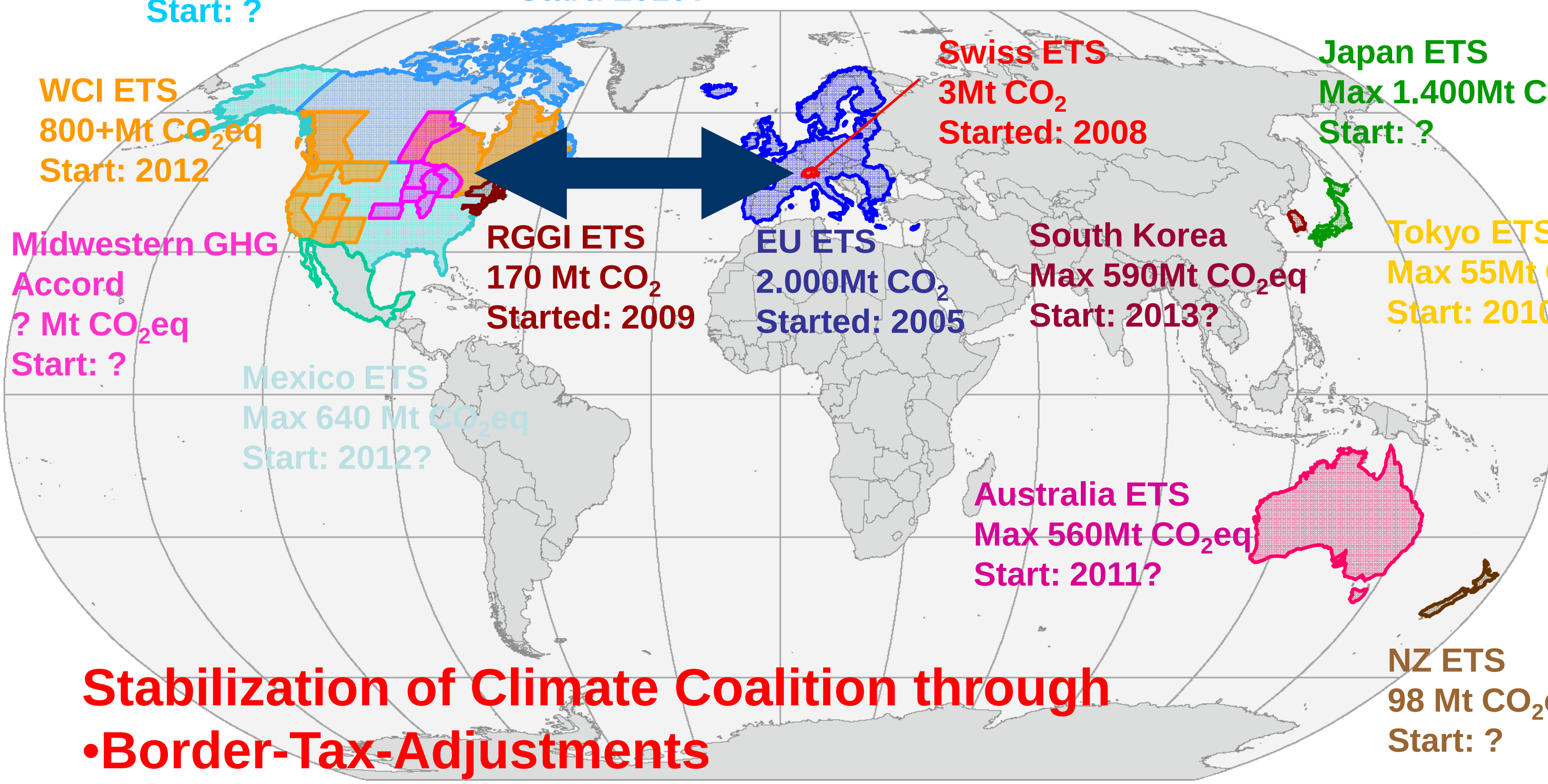
Any of these issues can be tackled..

- When assuming the perspective of someone
  who claims that mitigation is globally desirable
  - (in the sense of: after all information asymmetries being lifted, mitigation would appear as desirable 'on average')
- …no-mitigation appears as a failure of global governance…
- …that could be cured by suitable policy instruments.
- In some analogy to market failures tackled by economic instruments.
- Example: tackling the free rider problem by coalition formation:

European Contribution to Mitigation



Post Copenhagen: Potential ‘Plan B’: Linking of Regional CO_2-Trading Systems



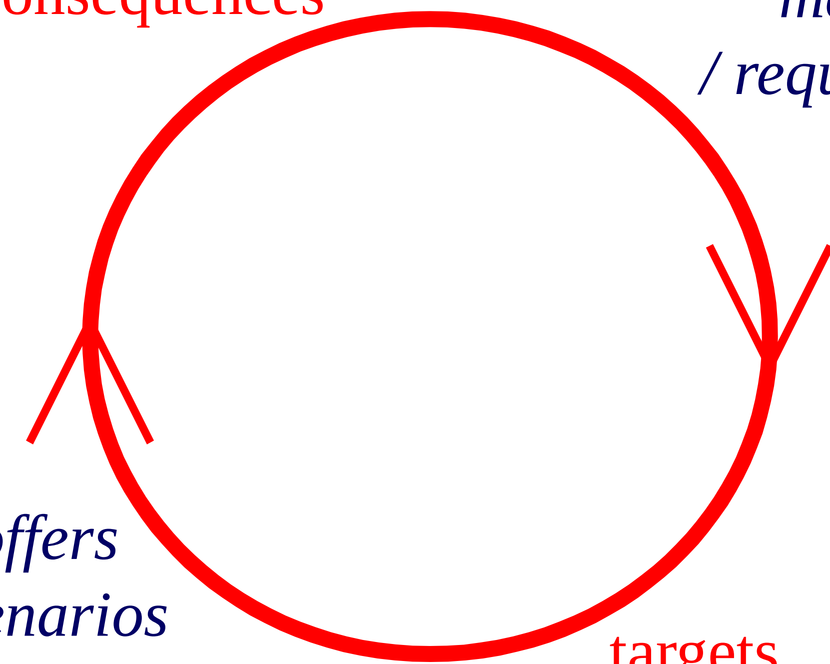
Stabilization of Climate Coalition through
- **Border-Tax-Adjustments**
- **Creating ‚Club-Goods‘ – eg Technology Protocols**

Source: Flachsland, Lessmann et al. (2009)

- Herald Tribune, Friday, January 23rd, 2009

Iteration of Policy Targets & Scenarios under Objective Boundary Conditions

Society judges on scenarios under the impression of main and side effects / requests further info on 'real life effects'



May refine targets

Academia offers solution scenarios

© Held (after IPCC-WGIII's / Edenhofer's 'enlightened pragmatic model', Edenhofer & Seyboth, 2014)

Summary

- In an idealized economy, the 2° target is compatible with continued economic growth.
  - The corresponding reduction of growth rate is 1-2 orders of magnitude smaller than the very growth rate.
  - A large folder of technologies is employed for this.
  - Mitigation investment decisions are crucial within the next 10 years.
- Uncertainty in climate sensitivity requires a hybrid decision instrument of cost effectiveness and cost benefit analysis.
  - Climate targets then less absolute.
  - The expected value of perfect climate information could be on the order of hundreds of billions € / year under a 2° target.
- A mitigation policy compatible with the 2° target requires tackling of a series of frictions.
  - For any of these there are good changes that subsequent policy instruments can be invented.