Potsdam Institute for
Climate Impact Research

Prof. Dr. Ottmar Edenhofer

Towards a Global Contract on Climate Change

Santa Fe, 24th July 2009

Summer School on Global Sustainability

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

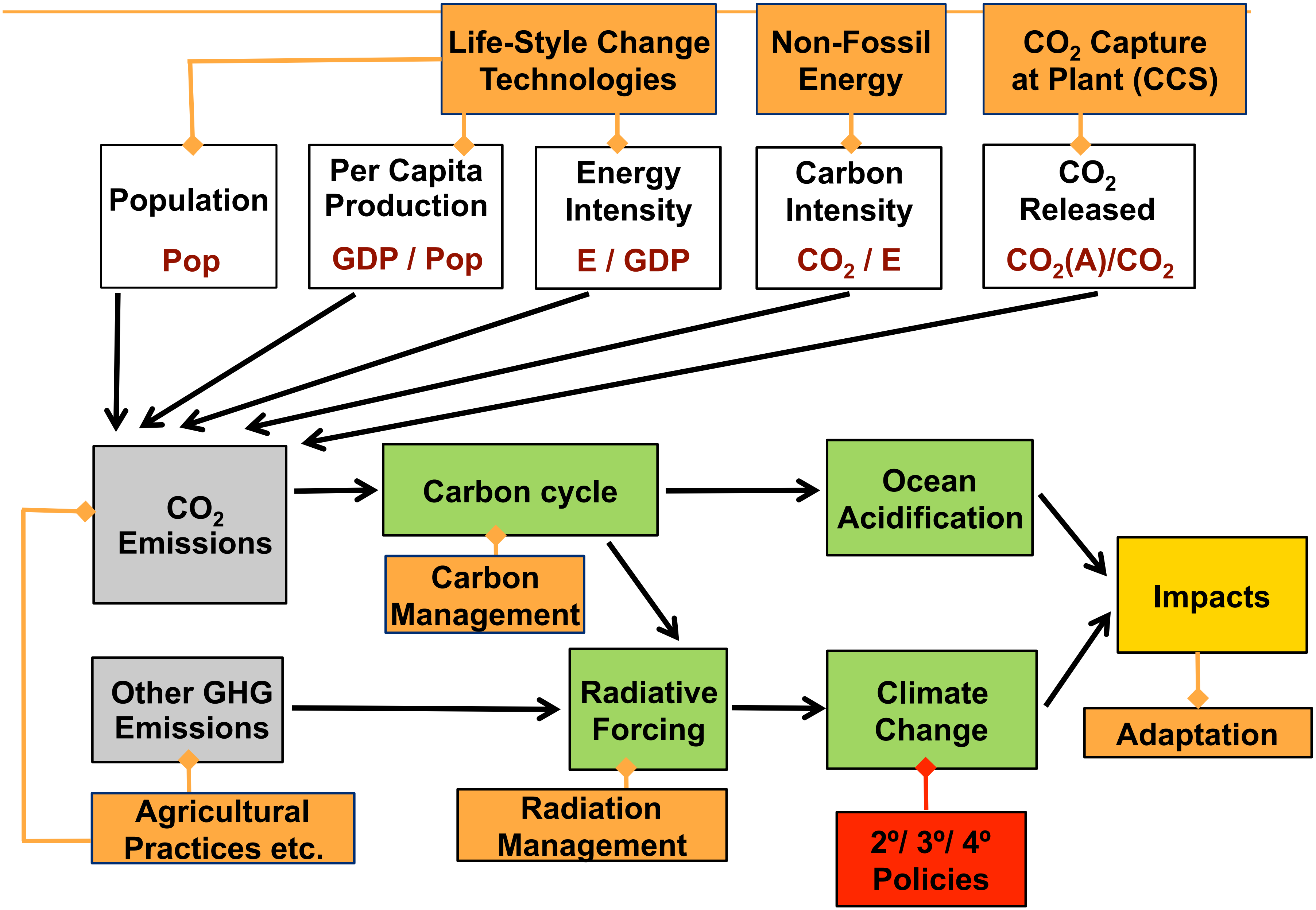
Working Group III
Mitigation of Climate Change

WMO

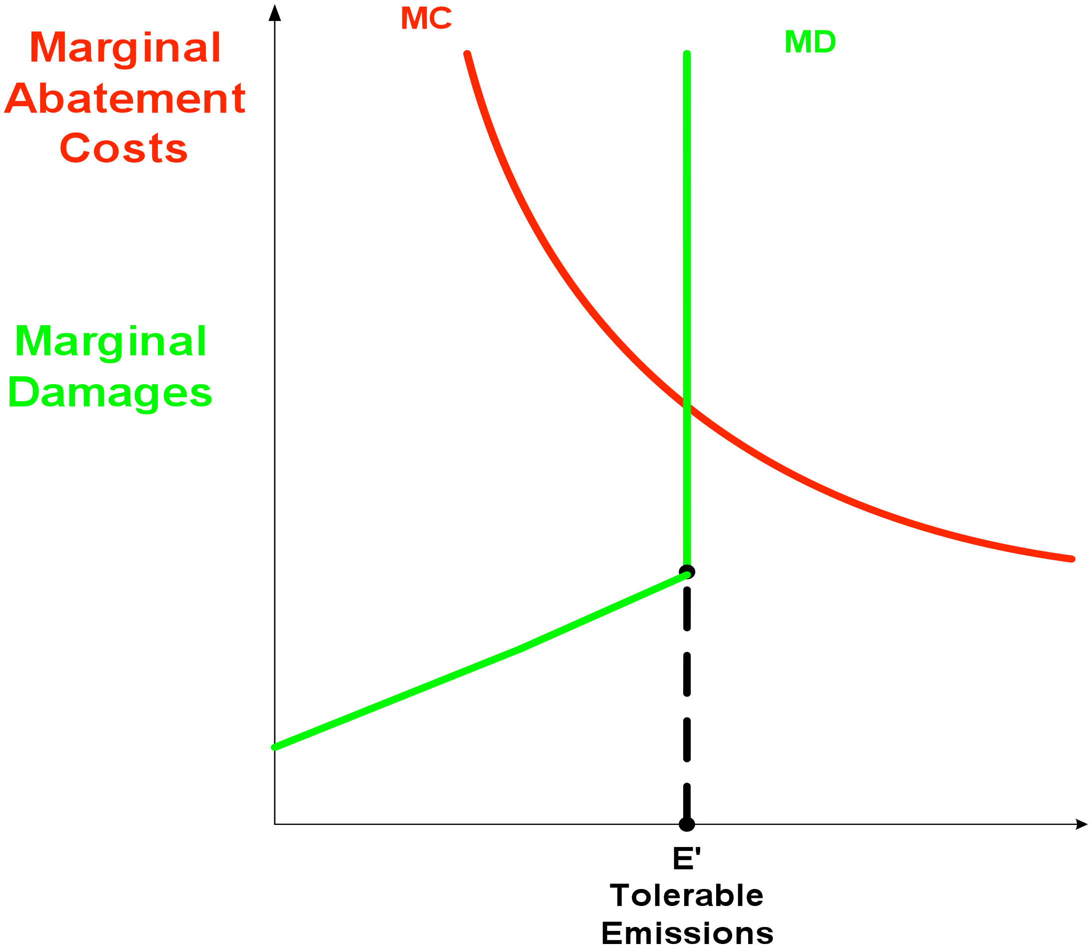
UNEP

Technische Universität Berlin

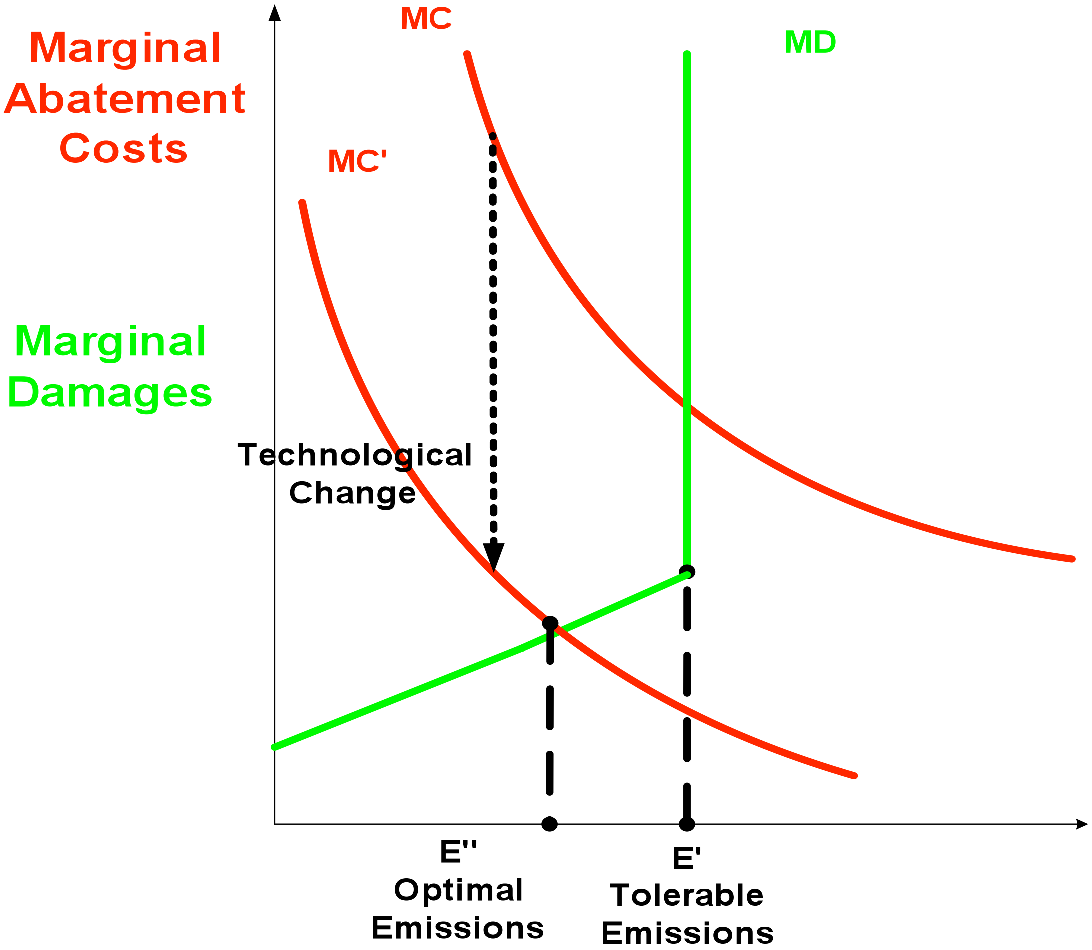
Assessing the Solution Space



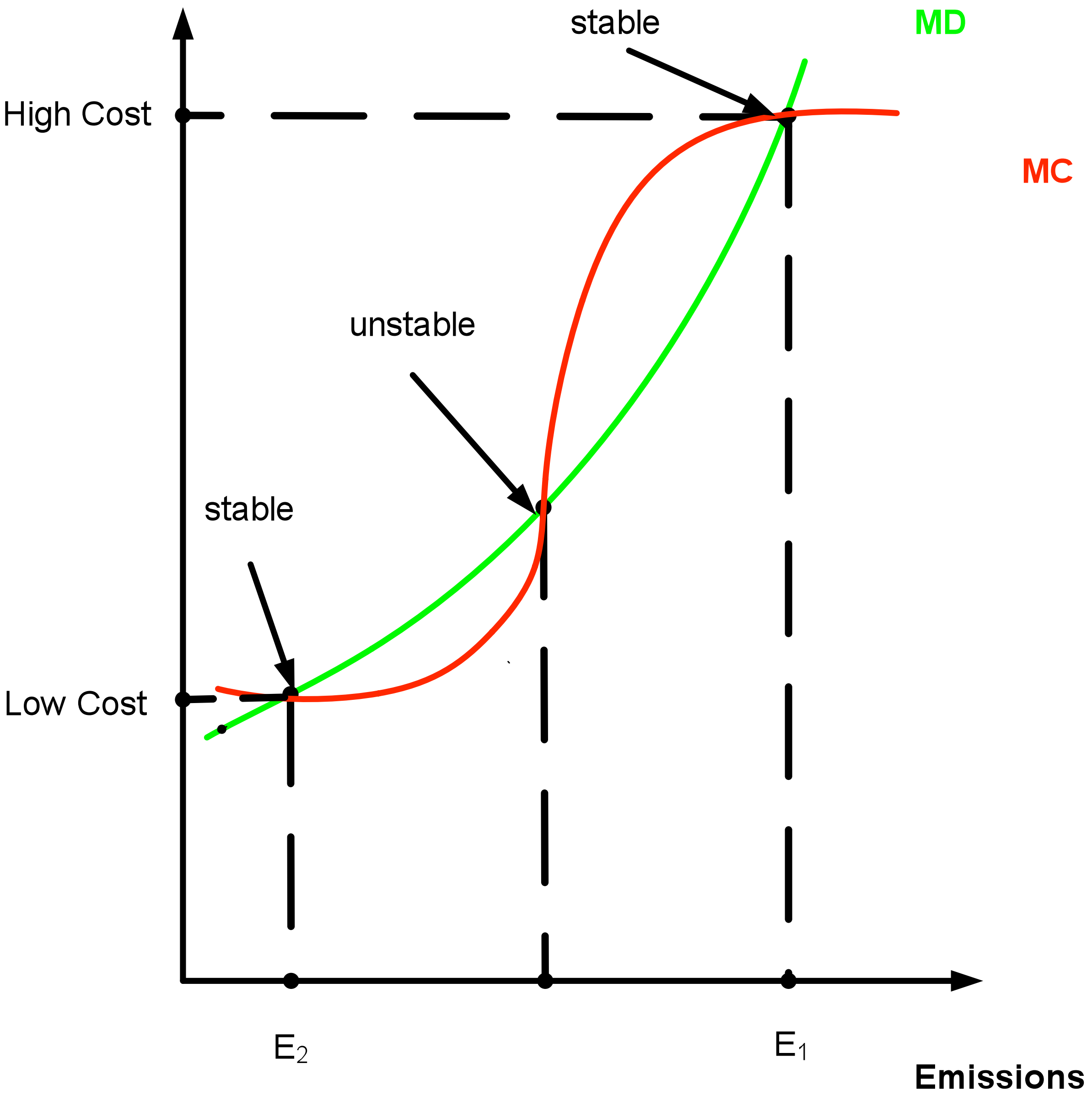
What about Tippint Points?



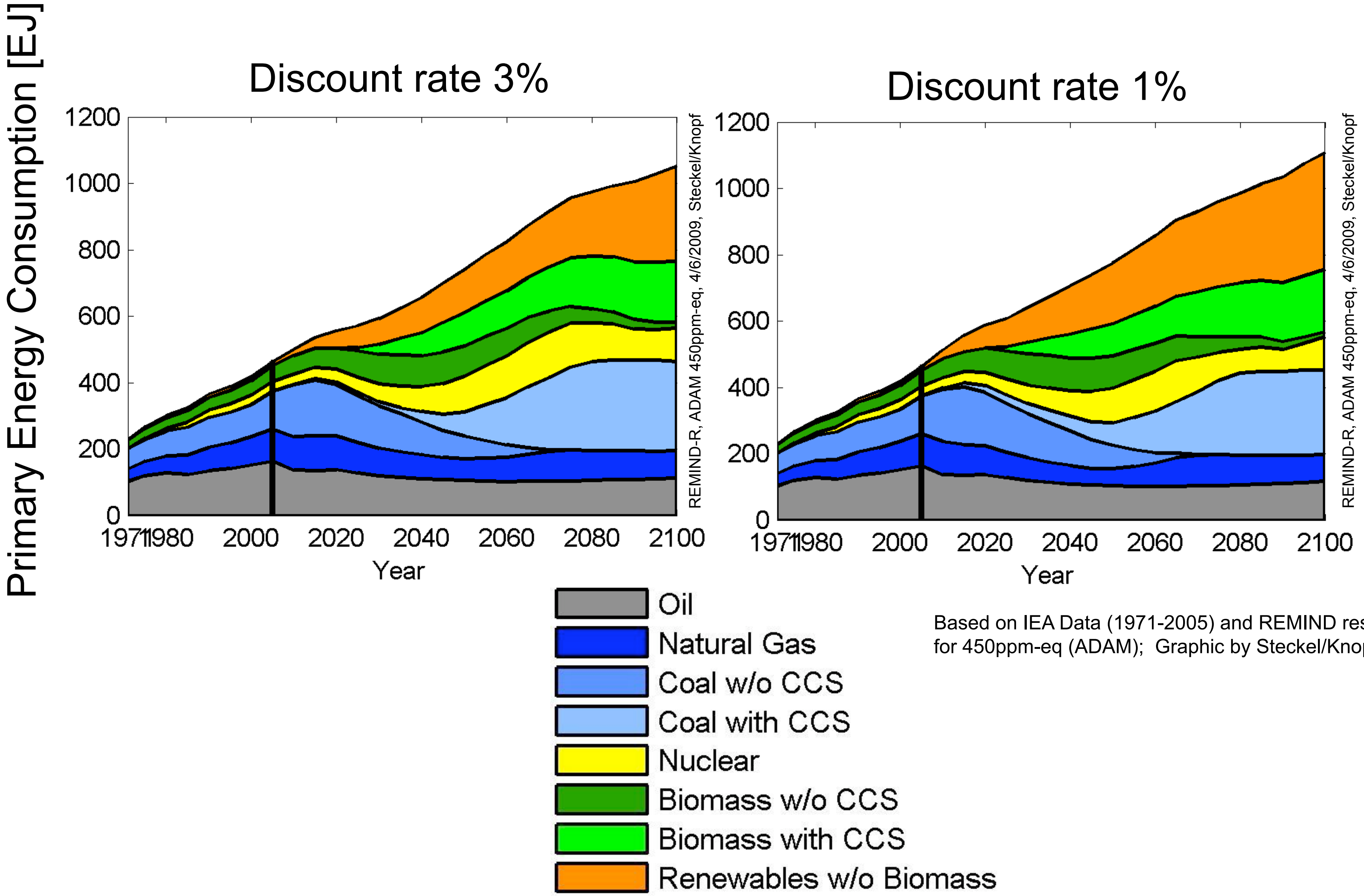
What about Technological Change?



Multiple Equilibria and Non-Convex Optimization

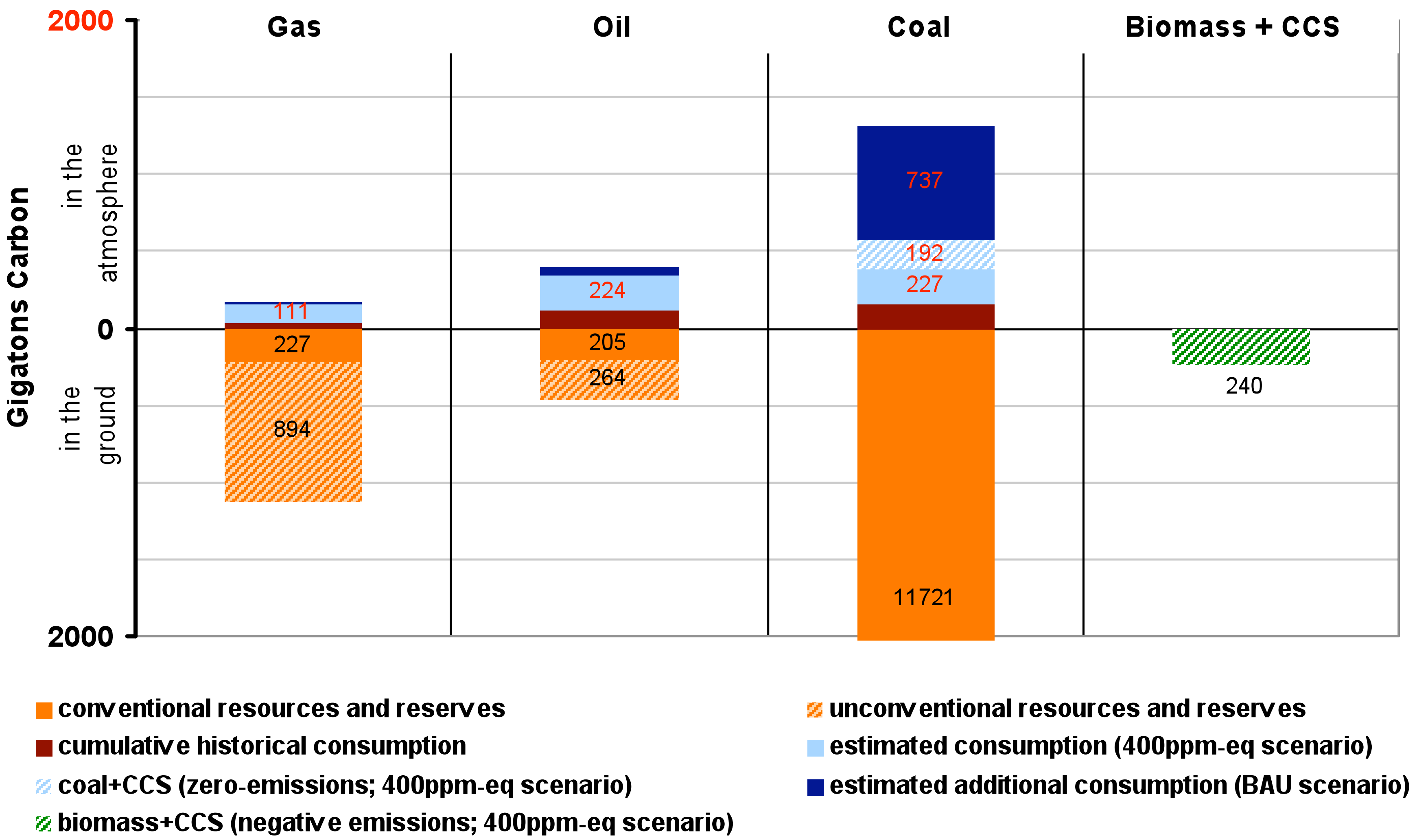


Discounting and Technological Change



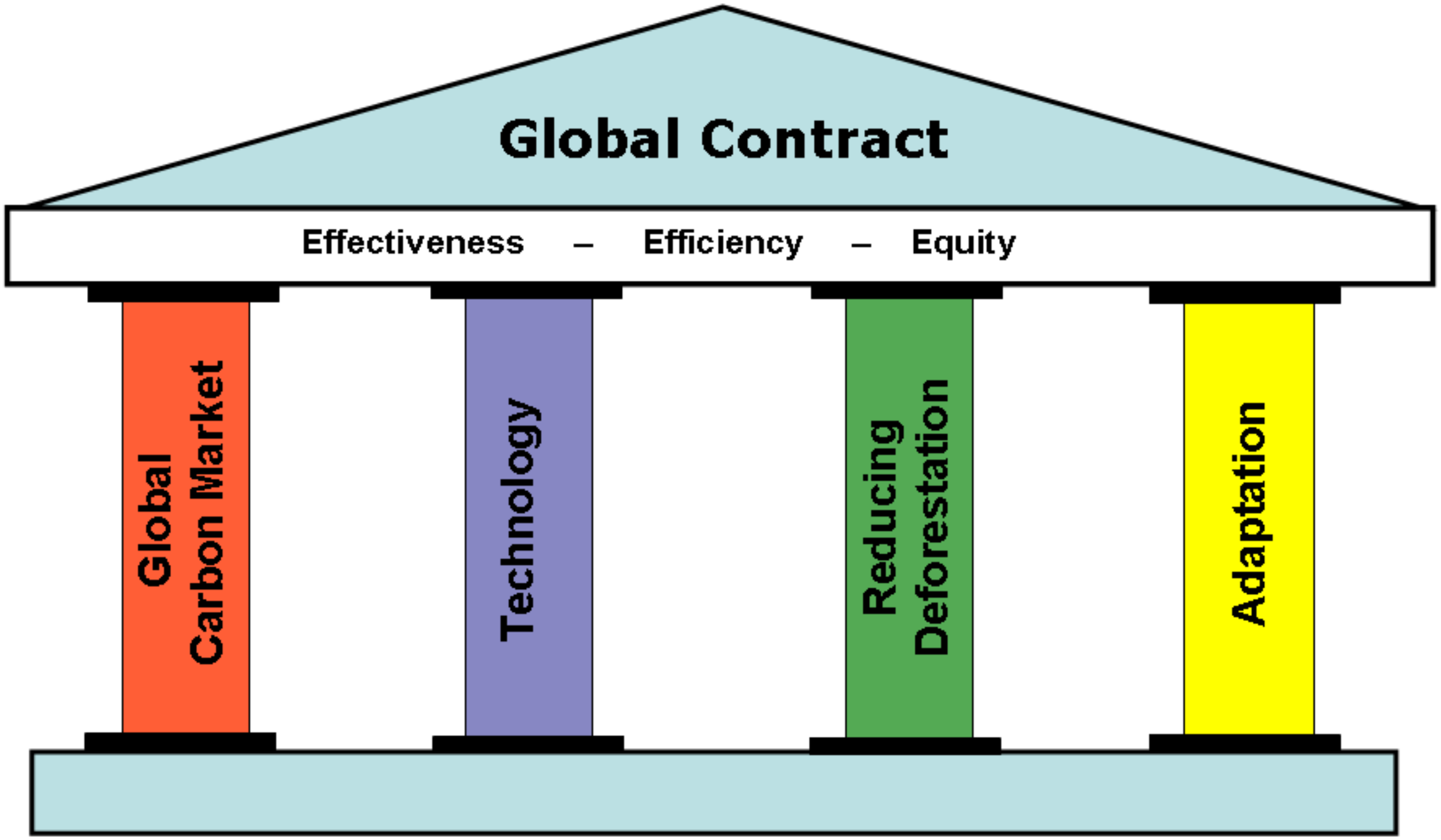
Based on IEA Data (1971-2005) and REMIND results for 450ppm-eq (ADAM); Graphic by Steckel/Knopf

The Neglected Supply Side

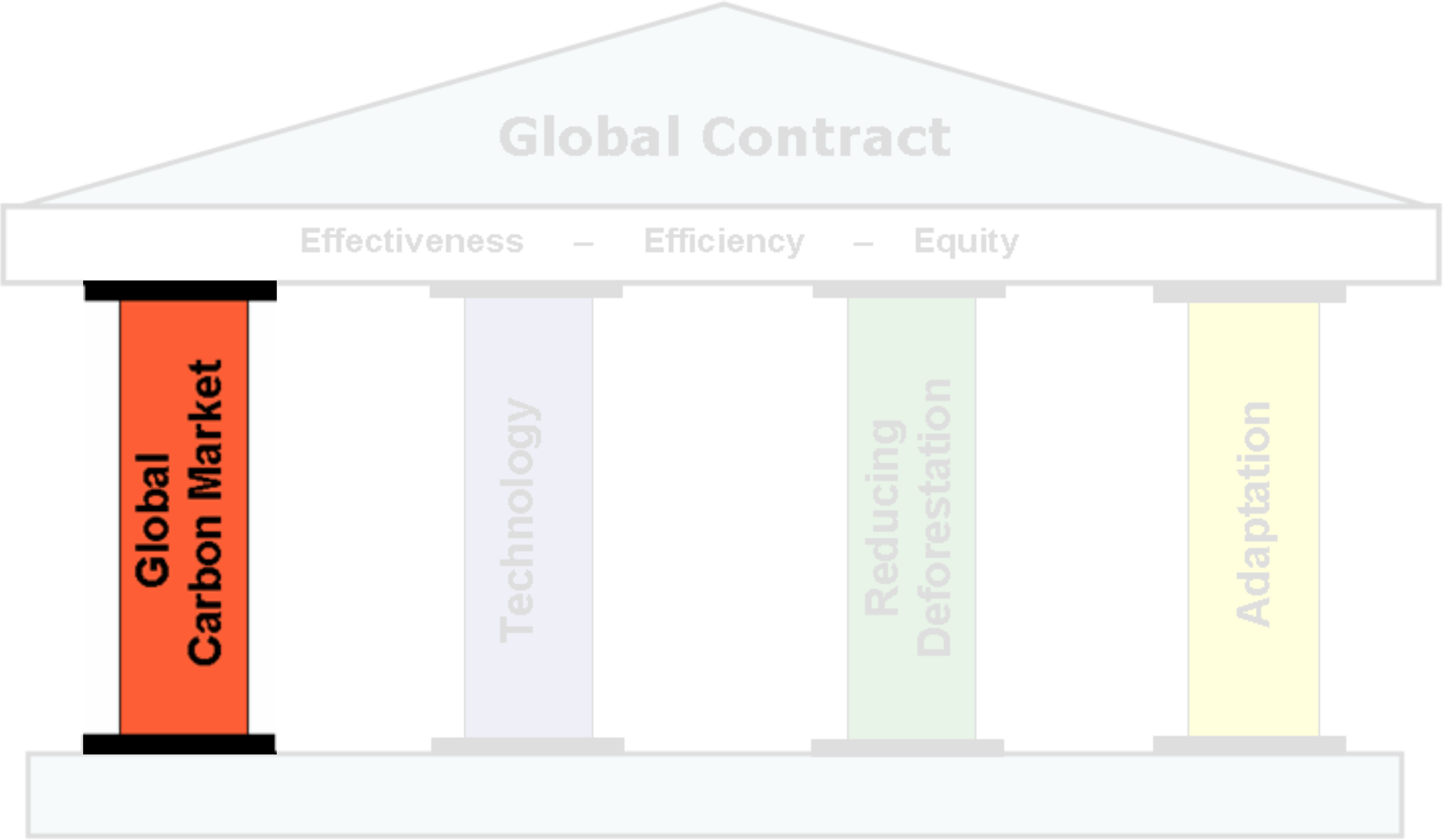


Edenhofer, Kalkuhl (2009)

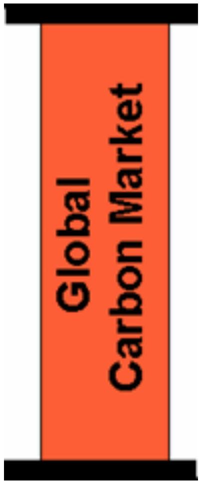
Architecture of a Global Contract



Architecture of a Global Contract

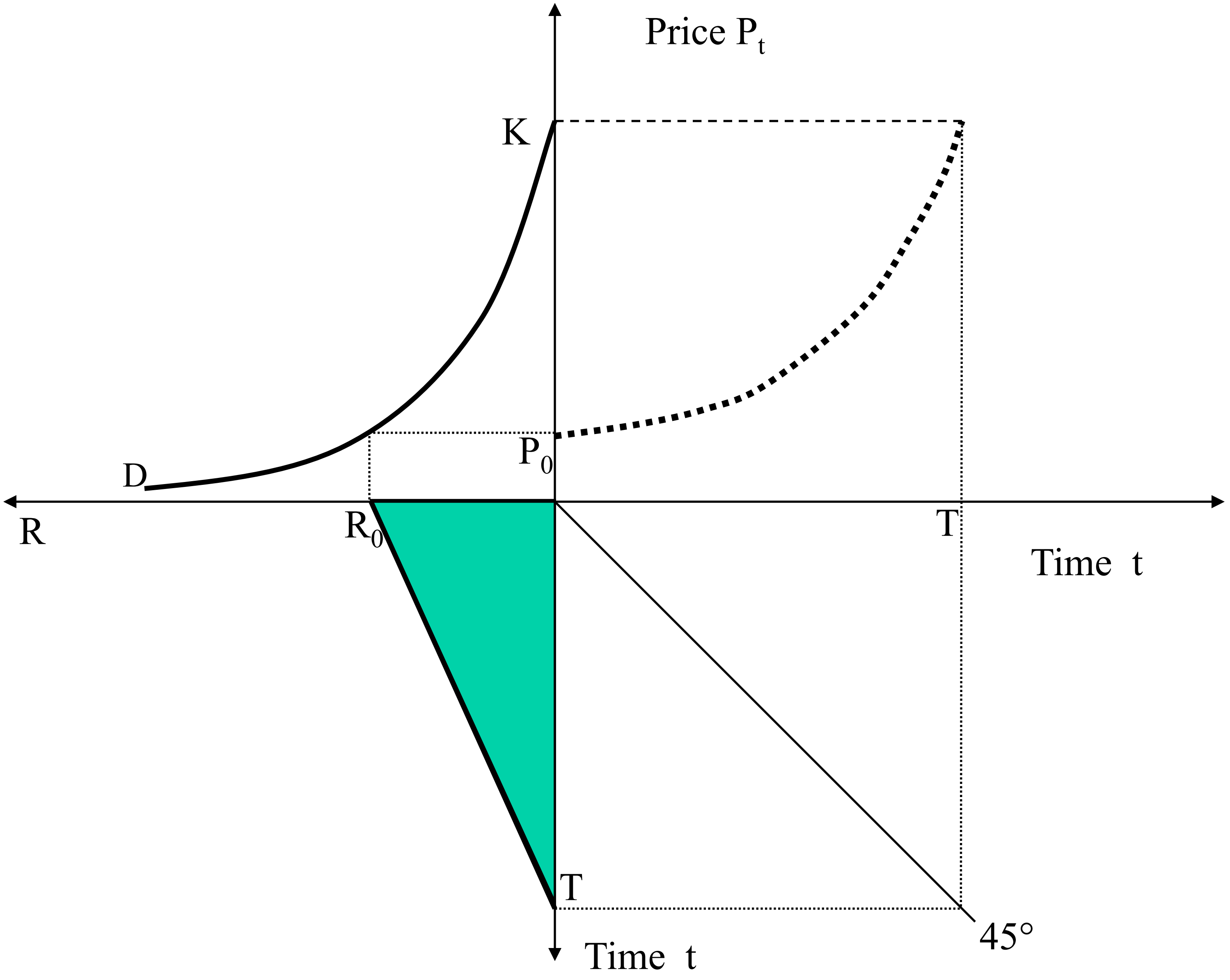


Towards a Global Carbon Market



1. The fundamental problem
2. Burden sharing
3. Delayed participation
4. Linking
5. EU ETS

The Hotelling Model



The “Green Paradox“ (Model)

Optimal resource extraction under climate change:

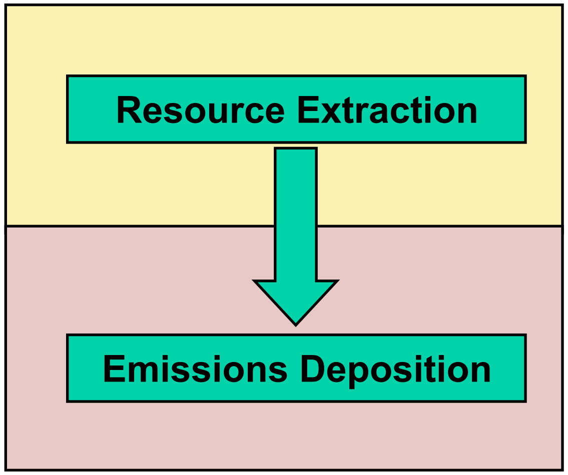
$$\max_{R_t} \int_0^\infty f(K_t, R_t, S_t) - g(S_t) e^{-rt} dt$$

K – capital
R – fossil resources
S – resource stock
f – production function
g – extraction costs

- Usual convexity conditions: $f_X>0, f_{XX}<0, g_S<0$
- f_S – marginal climate productivity depends on cumulative resource extraction (equals marginal damages); climate productivity additively separable
- Initial stock S_0 depletes with extraction: $\dot{S}_t = -R_t \;;\quad S_t \geq 0$
- Socially optimal Hotelling rule:

$$\boxed{r = \frac{\dot{f}_R + f_S}{f_R - g(S)}}$$

Lessons from the “Green Paradox“



Conventional Pigouvian tax cannot solve the incentive problem for stock-pollutant ➔ inefficient

***i*-th resource owner‘s problem:**

$$\max_{R_t^i} \int_0^\infty (p_t - g^i(S_t^i) - \tau_t) R_t^i e^{-rt} dt$$

p – resource price
R – fossil resources
S – resource stock
g – extraction costs
τ – unit tax

Pigouvian tax:

$$\tau_t = \tau(S_t) = \frac{f_S}{r}$$

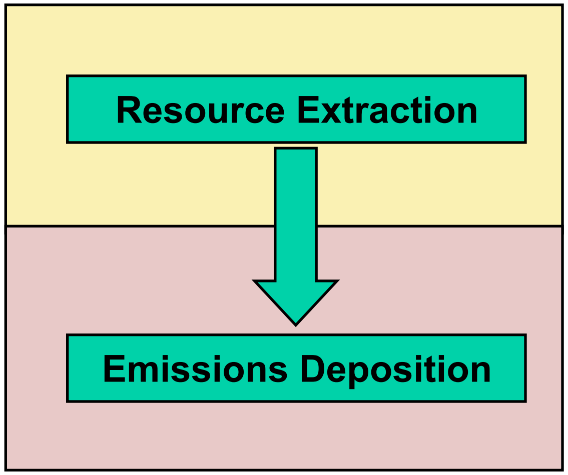
How do resource owners anticipate the change of τ ?

Pigouvian tax changes with aggregated, cumulative extraction!

But resource owners do only see a weak (or even no) relation between individual extraction and aggregated extraction

- **Conventional Pigouvian tax**
- **Central control of extraction**
- **Dynamic (non-linear) Pigouvian tax**
- **Decreasing cash flow tax or subsidies on non-extraction**
- **Capital source tax**
- **Emissions trading scheme**

Lessons from the “Green Paradox“



Conventional Pigouvian tax

Central control of extraction

Dynamic (non-linear) Pigouvian tax

Decreasing cash flow tax or subsidies on non-extraction

Capital income tax

Emissions trading scheme

Hotelling rule for the *i*-th resource owner with *n* identical resource owners and conventional Pigouvian tax:

$$r = \frac{\dot{p} + f_S + \boxed{\frac{f_{SS}}{r}\frac{n-1}{n}R}}{p - g(S)}$$

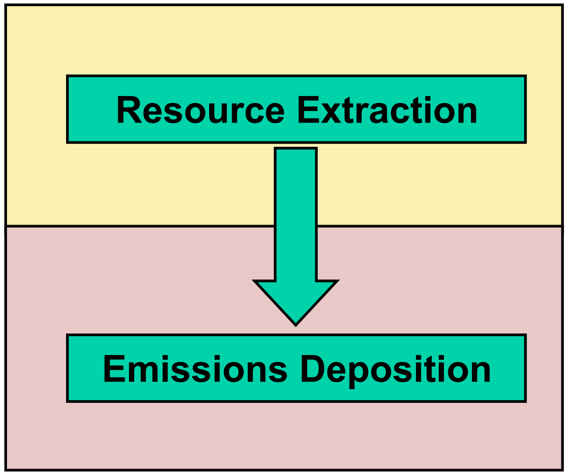
Suboptimal extraction path (“Green Paradox”)

- Acceleration of extraction due to $f_{SS}<0$
- Tax is inefficient and ineffective
- Resource sector suffers from internal public good problem with respect to $\tau(S_t)$

$$\tau(S_t) = \tau\left(\sum_{i=1}^{n} S_t^i\right) = \frac{f_S\left(\sum_{i=1}^{n} S_t^i\right)}{r}, \qquad \dot{S}_t^i = R_t^i$$

n=1	Correct anticipation of damages Tax as feedback instrument	$r = \frac{\dot{p} + f'_S}{p - g}$
n=∞	Only time-path is anticipated Tax as open-loop instrument	$r = \frac{\dot{p} + f_S + \frac{f_{SS}}{r}}{p - g(S)}$

Lessons from the “Green Paradox“



Central control of extraction and complete absorption of resource rent: Information and implementation problems

***i*-th resource owner‘s problem:**

$$\max_{R_t^i} \int_0^{\infty} (p_t(1-\varsigma_t) - g^i(S_t^i) - \tau_t) R_t^i e^{-rt} dt$$

Conventional Pigouvian tax

Central control of extraction

Dynamic (non-linear) Pigouvian tax

Decreasing cash flow tax or subsidies on non-extraction

Capital income tax

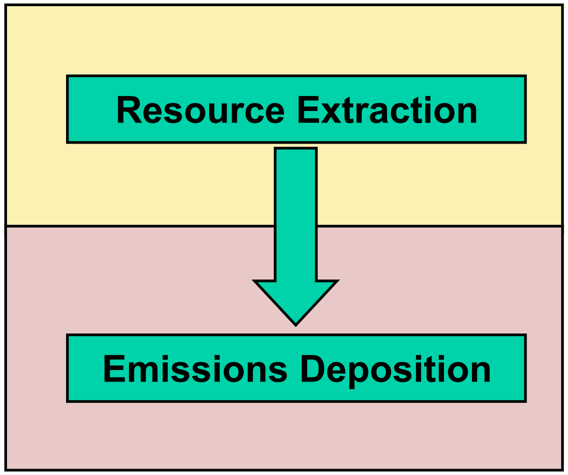
Emissions trading scheme

Tax regime:

$$\varsigma_t = 1, \quad \tau_t^i = g^i(S_t^i)$$

- 100% ad-valorem tax on resource price
- Tax refund for extraction costs
- No Hotelling dynamics in the resource sector
- Regulator has to decide in detail which resources when to extract (what are incentives for resource owners?)
- Information and implementation problems

Lessons from the “Green Paradox“



Conventional Pigouvian tax

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Capital income tax

Emissions trading scheme

Dynamic (non-linear) Pigouvian tax is optimal, but difficult to implement

***i*-th resource owner‘s problem:**

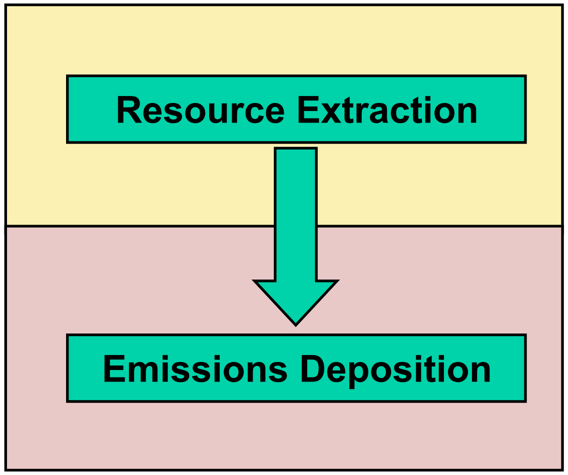
$$\max_{R_t^i} \int_0^\infty (p_t - g^i(S_t^i) - \tau_t(S_t^i)) R_t^i e^{-rt} dt$$

Pigouvian tax for i-th resource owners:
(*n* identical resource owners)

$$\tau(S_t^i) = \frac{f_S(nS_t^i)}{r}$$

- Tax changes with individual cumulative extraction
- Resource owners have to anticipate dynamic tax rule
- How to design tax for resource owners with heterogenous extraction costs?
- How to determine individual share of aggregate stock damage (for infinite time horizon)?

Lessons from the “Green Paradox“


Resource Extraction

Emissions Deposition

Conventional Pigouvian tax

Central control of extraction

Dynamic (non-linear) Pigouvian tax

Decreasing cash flow tax or subsidies on non-extraction

Capital income tax

Emissions trading scheme

Decreasing cash flow tax or subsidies on non-extraction: Credibility and commitment problems

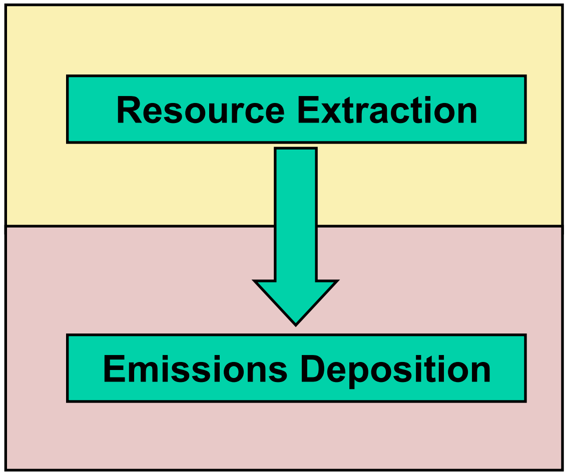
$$\max_{R_t} \int_0^\infty (p_t - g(S_t))(1-\theta_t) R_t e^{-rt} dt$$

Optimal cash flow tax:

$$\dot{\theta}_t = \frac{-f_S^*}{p^* - g(S^*)}(1-\theta_t) < 0$$

- Decreasing tax ($f_S<0$, $\theta<1$)
- Regulator has to know optimal trajectories p^*, S^*, f_S^*
- Regulator has to commit to tax path credibly for the entire (infinite) time horizon
- Regulator has to determine θ_0 (θ will turn into a subsidy if θ_0 is choosen to small)
- Same problems for time-path altering unit or ad-valorem taxes or stock subsidies

Lessons from the “Green Paradox“



Conventional Pigouvian tax

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Capital income tax

Emissions trading scheme

Capital income tax: Limited effectivity and distortions on capital markets.

$$\max_{R_t} \int_0^{\infty} (p_t - g(S_t)) R_t e^{-r\underline{(1-v_t)}t} dt$$

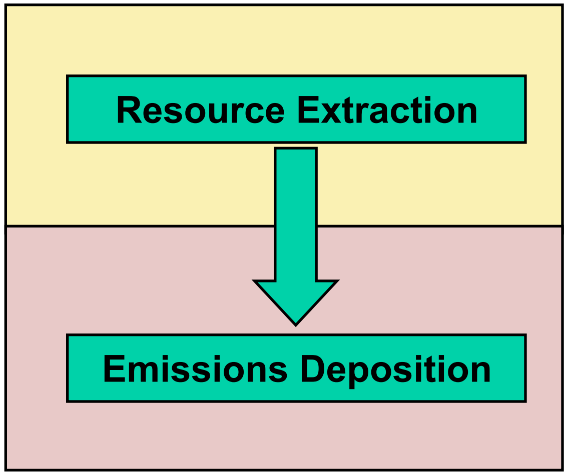
capital tax

Optimal capital tax (Sinn 2008)**:**

$$v_t = \frac{f_S}{r(p - g(S))}$$

- High capital taxes flatten extraction path
- Distortions on capital markets (welfare losses)
- Capital tax might not work for ambitious mitigation target or backstops (zero extraction in the long run)
- International harmonization of existing capital taxes and closing down tax havens help to slow down extraction

Lessons from the “Green Paradox“



Conventional Pigouvian tax

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Emissions trading scheme

Conventional Pigouvian tax cannot solve the incentive problem for stock-pollutant ➔ inefficient

Control of extraction and complete absorption of resource rent ➔ information and implementation problems

Dynamic (non-linear) Pigouvian tax is optimal but difficult to implement

Decreasing cash flow tax or subsidies on non-extraction: Credibility, commitment and distribution problems

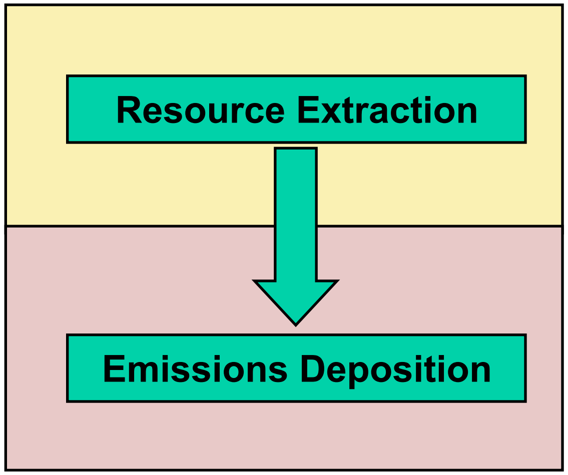
Capital income tax: Limited effectivity, vulnerable to other distortions on capital markets

➔ Internalizing damages might not be feasible !

➔ “Decentralized“ extraction-deposition problem of carbon stocks might not exist !

➔ Emissions trading scheme – an alternative ?

Lessons from the “Green Paradox“



Conventional Pigouvian tax

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Capital income tax

Emissions trading scheme

Emissions trading scheme (ETS):

- Determines aggregated extraction path
- But leaves flexibility to resource owners:
  - What-Flexibility: coal, oil, gas, conventional/ unconventional
  - When-Flexibility: if intertemporal flexibilty is implemented

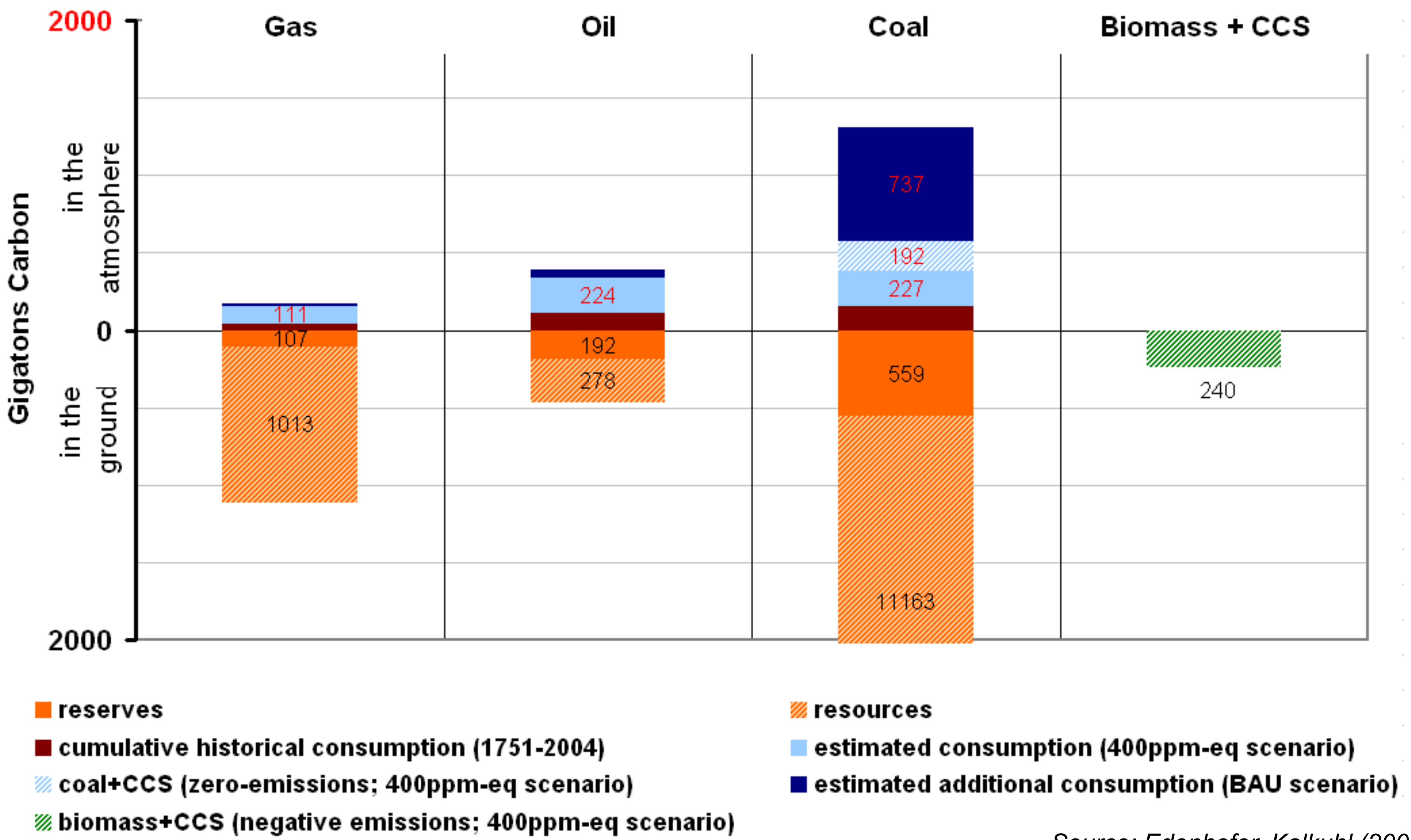
➔ How to determine caps?

➔ How to organize intertemporal permit trade?

➔ What happens to the resource rents?

... to be explored

Carbon Stocks – In Ground and Atmosphere



Source: Edenhofer, Kalkuhl (2009)

Emissions Trading with Carbon Budget

Resource sector:

$$\max_{R_t} \int_0^T (p_t - g(S_t))R_t e^{-rt} dt$$

s.t. $\dot{S}_t = -R_t$

f.o.c. $p_t = \lambda_t - g(S_t)$

$\dot{\lambda}_t = r\lambda_t + g_S(S_t)R_t$

transv. c. $S_T \lambda_T = 0$

Permit market:

$$\max_{R_t} \int_0^T a_t R_t e^{-rt} dt$$

s.t. $\dot{A}_t = -R_t$

f.o.c. $a_t = \mu_t$

$\dot{\mu}_t = r\mu_t$

transv. c. $A_T \mu_T = 0$

As the permit stock is scarce, i. e. $A_0 < S_0$, the entire permit stock is used ($A_T=0$) while the resource stock is not exhausted completely ($S_T>0$)

Due to the transversality condition in the resource sector, $\lambda_T=0$, i. e. there is no resource scarcity rent in the final period

Resource extraction is dominated by the permit market

Emissions Trading with Carbon Budget

Resource sector:
(resource rent)

$$\lambda_t = -\int_t^T g_S(S_t) R_t e^{r(t-s)} ds$$

- Zero extraction rent for constant extraction costs
- Policy reduces $-g_S(S_t)$ and R_t, and thus the extraction rent
- Pure scarcity rent is removed by policy as $\lambda_T=0$

➔ Small extraction rent for resource owners

Permit market:
(permit rent)

$$\mu_t = a_t = a_0 e^{rt}$$

- Pure scarcity (Hotelling) price a_t for permits from the exhaustible stock
- Calculation of a_0 requires the assessment of optimal demand, extraction costs and extraction rent λ_t

➔ Large scarcity rent for permit owners / regulator

Emission Trading within a Cost-Benefit Framework

- Full intertemporal flexibility (i. e. free banking and borrowing) leads to Hotelling path for the **permit price** a_t:

$$a_t = a_0 e^{rt}$$

- The optimal **carbon price** path p_t, however, has to consider damage dynamics:

$$r = \frac{\dot{p}_t + f_S}{p_t - g(S_t)}$$

- Intertemporal **exchange rate** integrates stock-damage into intertemporal arbitrage for permit trade:

$$\sigma_t = \frac{f_S^{\ *}}{\int_t^T f_S^{\ *} e^{r(t-s)} ds + \frac{f_S^{\ *}(T)}{r} e^{r(t-T)}}$$

- **Initial permit stock**:

$$b_0 = S_0 - \frac{\int_0^T S_t^* f_S^{\ *} e^{r(t-s)} ds + \frac{f_S^{\ *}(T)}{r} e^{r(t-T)} S_T}{\int_0^T f_S^{\ *} e^{r(t-s)} ds + \frac{f_S^{\ *}(T)}{r} e^{r(t-T)}}$$

- **Permit bank**:

$$\dot{b}_t = -R_t + \sigma_t b_t$$

Intertemporal Exchange Rate

Problems with exchange rates:

$$\sigma_t = \frac{f_S^{\,*}}{\int_t^T f_S^{\,*} e^{r(t-s)} ds + \frac{f_S^{\,*}(T)}{r} e^{r(t-T)}}$$

$$b_0 = S_0 - \frac{\int_0^T S_t^* f_S^{\,*} e^{r(t-s)} ds + \frac{f_S^{\,*}(T)}{r} e^{r(t-T)} S_T}{\int_0^T f_S^{\,*} e^{r(t-s)} ds + \frac{f_S^{\,*}(T)}{r} e^{r(t-T)}}$$

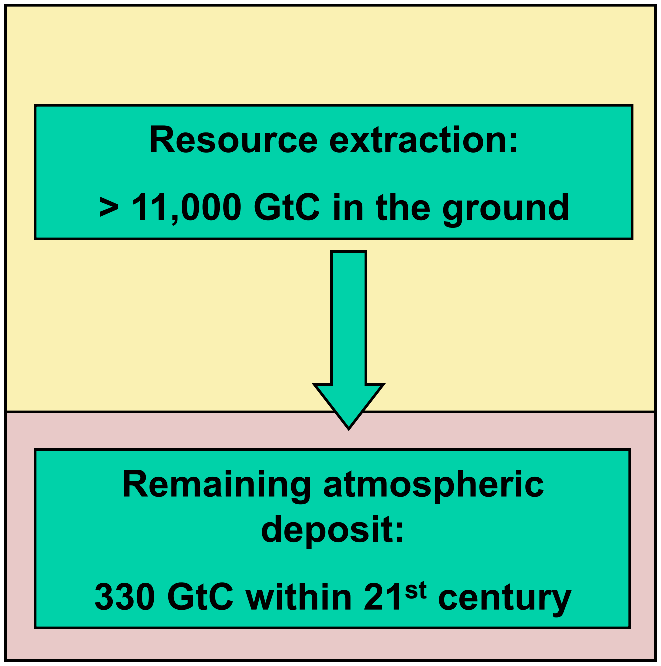
$$\dot{b}_t = -R_t + \sigma_t b_t$$

- Daunting informational requirements for the regulator
  - Optimal extraction / damage path has to be known
- The ex-post cumulative permit quantity is determined endogenously by market’s banking and borrowing decisions
  - Suboptimal arbitrage destabilizes the mitigation target

➔ **Difficult to achieve optimal timing with intertemporal flexibility for markets**

➔ **Find pragmatic solutions**

Why We Could Need a Central Carbon Bank



Resource extraction:

> 11,000 GtC in the ground

Remaining atmospheric deposit:

330 GtC within 21st century

Issuing of permits in accordance with the remaining atmospheric deposit:

- Dividing the global budget into national budgets by international negotiations
- International and intersectoral permit trade for a cost-effective achieving of the budget
- National carbon banks guarantee long-term credibility of the budget

Manage timing:

- National carbon banks could set the time path directly
- National carbon banks could set intertemporal exchange rates and give intertemporal flexibility to the market

Budget Approach and A Simple Allocation Rule

$$C_{nat} \equiv \int_{T_1}^{T_2} E_{nat}(t)\,dt = C_{glob}(p)\,\frac{M_{nat}(T_M)}{M_{glob}(T_M)}$$

national CO_2 budget = national emissions between T_1 and T_2 = global CO_2 budget * share of population M in base year T_M

4 Parameters for multi-lateral negotiations:

- T_1: starting point, e.g. 1850 or 1990 or 2000
- T_2: end of negotiation period, e.g. 2050 or 2100
- p: probability for keeping the 2°C target
- T_M: e.g. 2010 to avoid „population policy“ by climate policy

WBGU 2009

„World Formula“

$$C_{nat} \equiv \int_{T_1}^{T_2} E_{nat}(t)\,dt = C_{glob}(p)\,\frac{M_{nat}(T_M)}{M_{glob}(T_M)}$$

national CO_2 budget = national emissions between T_1 and T_2 = global CO_2 budget * share of population M in base year T_M

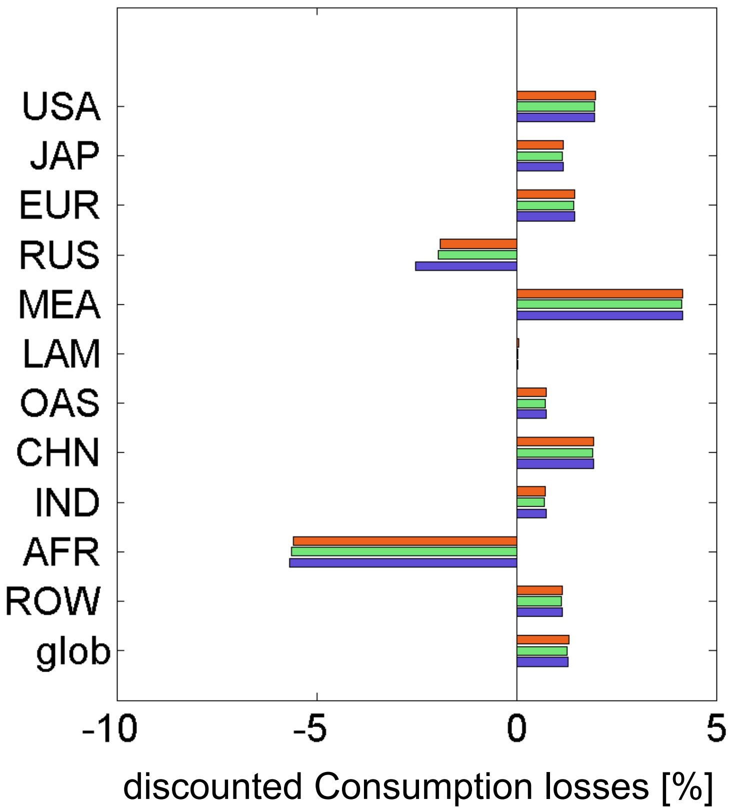
Possible Parameters (e.g. in the WBGU approach)

- T_1: 2010
- T_2: 2050
- p: 66%
- T_M: 2010

WBGU 2009

Regional Mitigation Costs with Budget Approach

Regional budgets according to per capita allocation



🟦 2°C target
🟩 budget until 2100
🟧 budget until 2050 and 2050-2100

Budget distributed according to mean per capita 2005-2050

Parameters here
- T_1: 2005
- T_2: 2050 or 2100
- p: 75%
- T_M: mean 2005-2050

© Lüken

How to Allocate Emission Rights?

Possible guiding ethical principles:

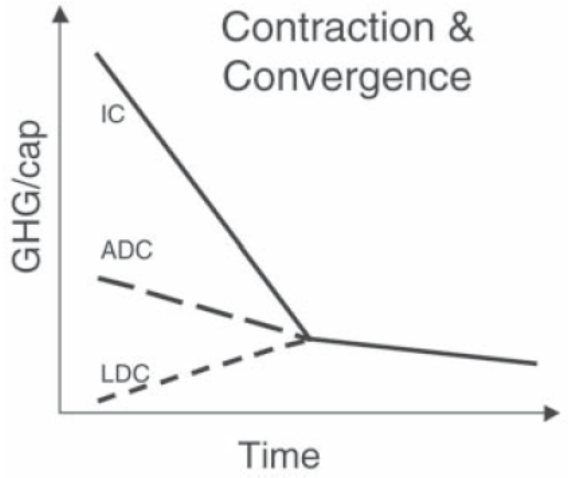
- Egalitarian
- Ability to pay
- Historic responsibility (or polluter pays principle)
- Sovereignty

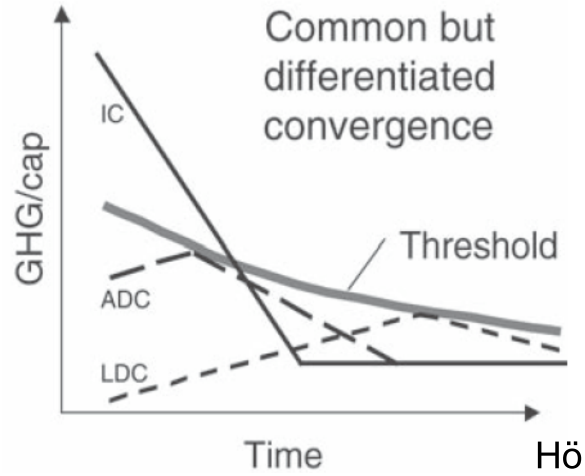
Adopted from
den Elzen and Lucas, 2005

How to Allocate Emission Rights?

Possible allocation rules e. g.:

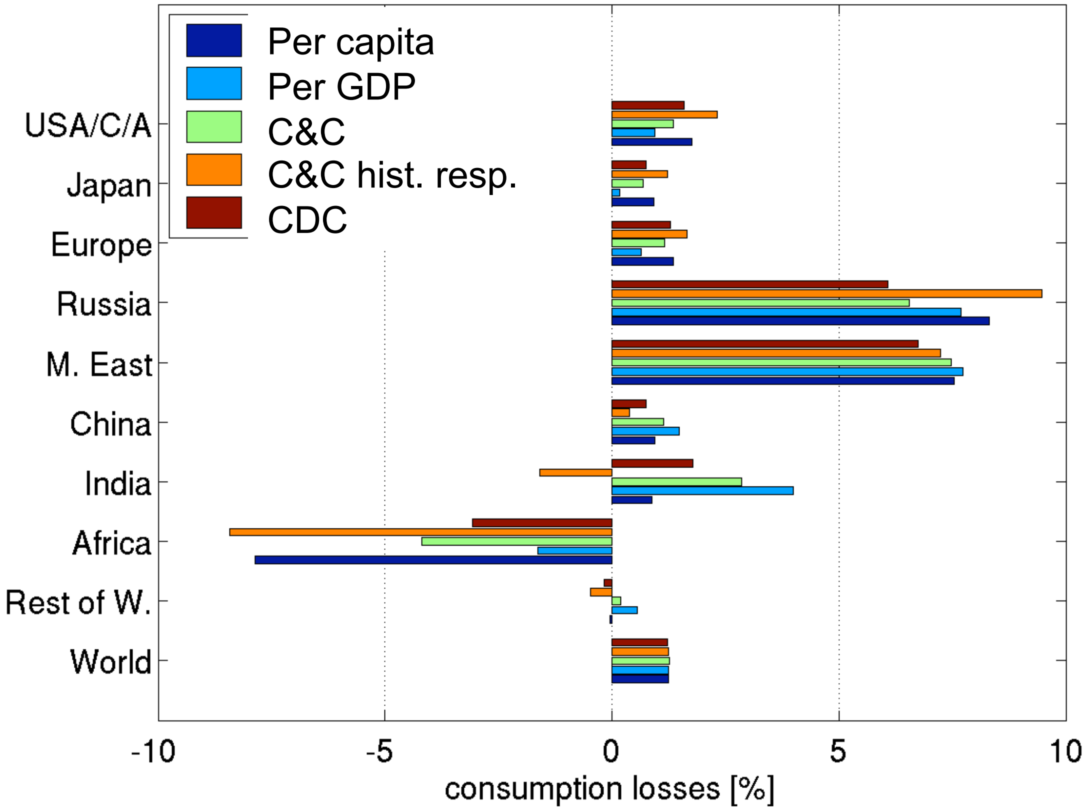
- Contraction & convergence (C&C)
- C&C including historic emissions (C&C hist resp)
- Common but differentiated convergence (CDC)





Höhne et al., 2006

Regional Mitigation Costs and Rent-Seeking



© Knopf

Will permit trade create new rent-seeking economies?

Technology and Rent-Seeking

- How are results influenced by assumptions on
  - the initial permit allocation
  - Type of climate target

- Understand and quantify domestic effects, energy trade effects, permit trade effects on regional mitigation costs by a new *economic decomposition* method

→ We need a model with an appropriate representation of inter-regional interactions and high technological resolution.

Determinants of Regional Mitigation Costs

Allocation Emissions Carbon Prize

$$\Delta C = D + T - \int_{t0}^{T} \underbrace{\exp(-\rho t)(A(t) - E(t))\,p(t)\,dt}_{\text{Carbon trade balance}}$$

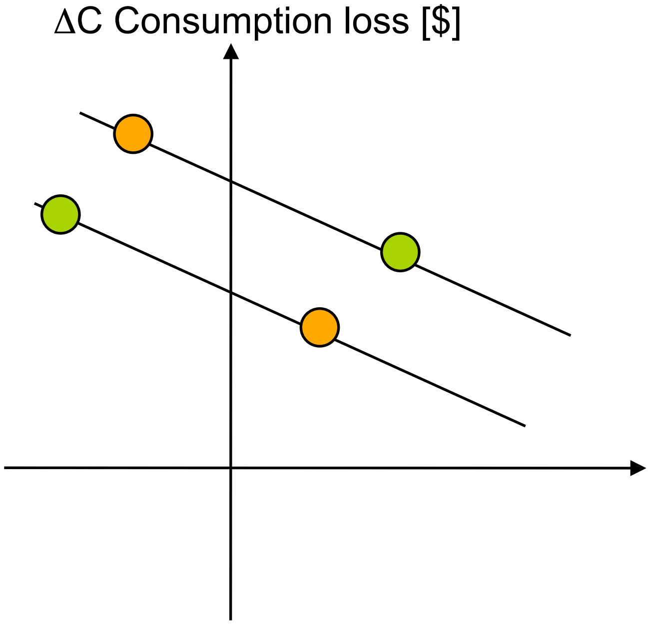
Domestic Effect

Energy Trade Effect

Carbon Trade Effect

Lüken et al. (2009)

Effects on Regional Mitigation Costs



Influence of Initial Permit Allocation:

pure redistribution!

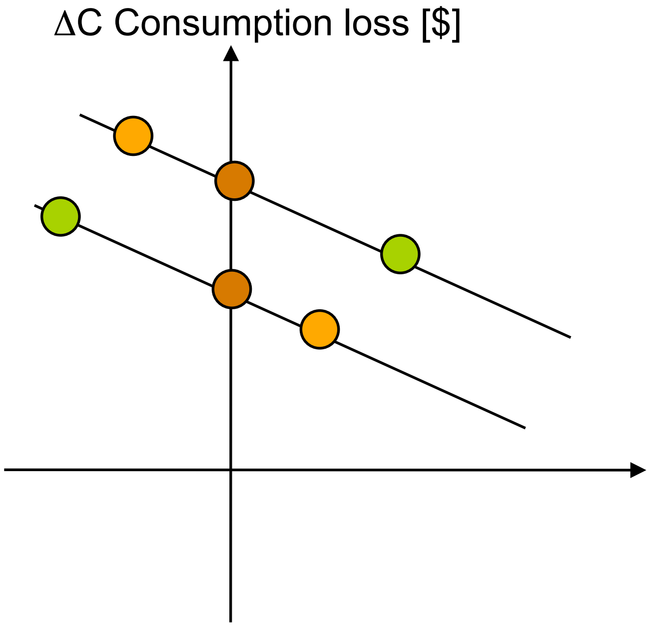
2nd theorem of welfare:
free flow of capital
→ *separability* of equity and efficiency

Allocation Emissions Carbon Prize

$$\Delta C = D + T - \int_{t0}^{T} \underbrace{\exp(-\rho t)(A(t) - E(t))\,p(t)\,dt}_{\textbf{Carbon trade balance}}$$

Lüken et al. (2009)

Effects on Regional Mitigation Costs



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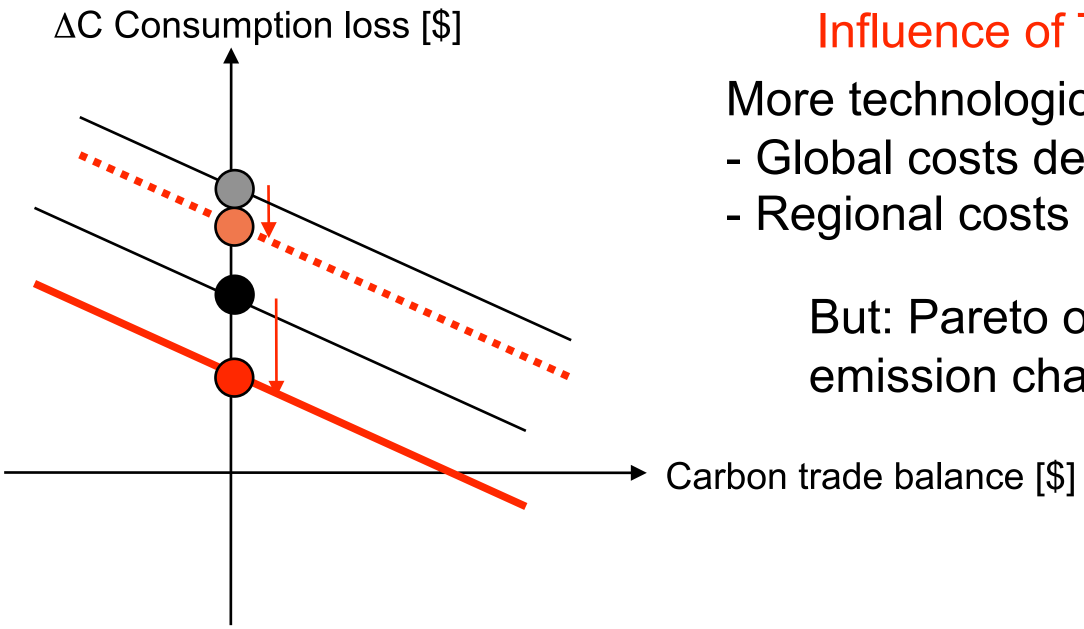
→ *separability* of equity and efficiency

$$\Delta C = D + T - \int_{t0}^{T} \underbrace{\exp(-\rho t)(A(t) - E(t))\,p(t)\,dt}_{\text{Carbon trade balance}}$$

● **: Carbon trade balance = 0**

Lüken et al. (2009)

Effects on Regional Mitigation Costs



Influence of Technology:

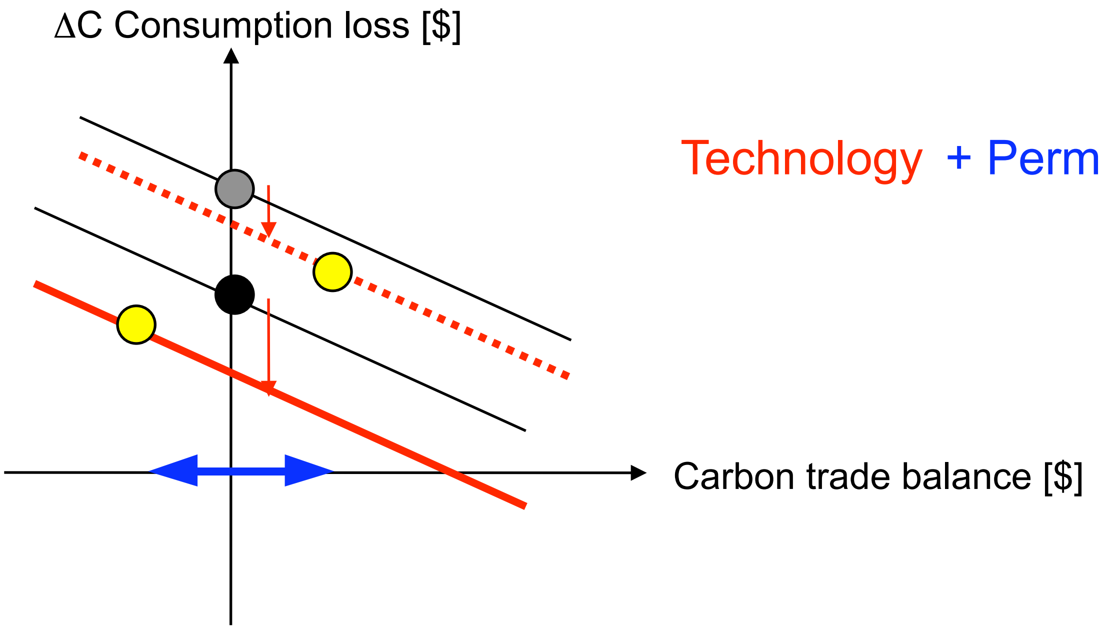
More technological flexibility →
- Global costs decrease
- Regional costs generally decrease

But: Pareto optimal sharing of emission changes!

$$\Delta C = D + T - \underbrace{\int_{t0}^{T} \exp(-\rho t)(A(t) - E(t))\,p(t)\,dt}_{\substack{\text{Carbon trade balance} \\ \mathbf{= 0}}}$$

Lüken et al. (2009)

Effects on Regional Mitigation Costs



Technology + Permit Allocation

$$\Delta C = D + T - \int_{t0}^{T} \underbrace{\exp(-\rho t)(A(t) - E(t))p(t)dt}_{\text{Carbon trade balance}}$$

Lüken et al. (2009)

Decomposition of Cumulative Consumption Effects

- Macro Economic Budget (cumulated over time):

(1) $\sum_t (Y - X_G) = \sum_t (C + I + G_{ESM})$ for all regions

- Intertemporal Trade Balance:

(2) $\sum_t (p_G X_G + p_E X_E + p_P X_P) = 0$ for all regions

- Combine (1) and (2), calculate aggregate differences of policy scenario and reference scenario for all regions:

$$\Delta C = \underbrace{\Delta Y - \Delta I - \Delta G_{ESM}}_{\text{domestic effect}} \underbrace{+ \Delta X_E}_{\text{energy trade effect}} \underbrace{+ \Delta X_P}_{\text{permit trade effect}}$$

(subtract extraction costs from energy trade effect)

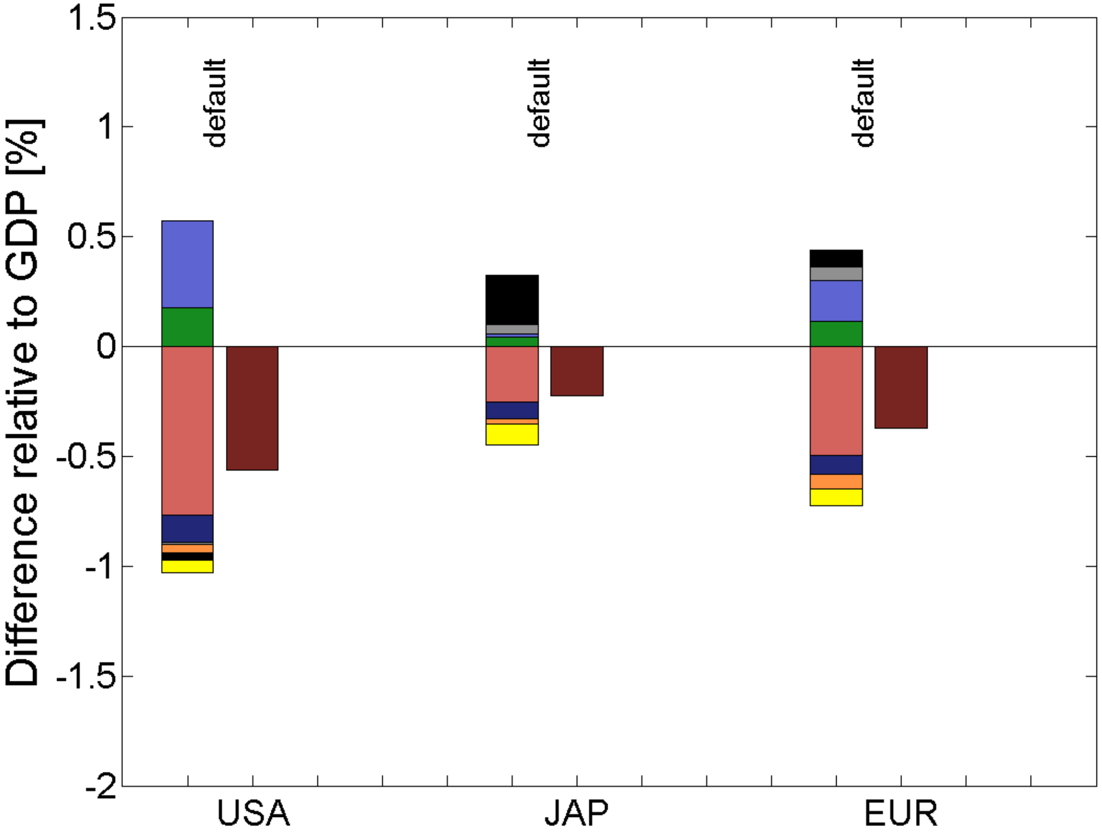
Lüken et al. (2009)

Scenarios

- *default scenario*: 2 °C climate target
- *nucfix*: nuclear restricted to reference scenario level
- *renewfix*: renewables restricted to reference scenario level
- *ccsmin*: CCS restricted to 100 GtC cumulated

Lüken et al. (2009)

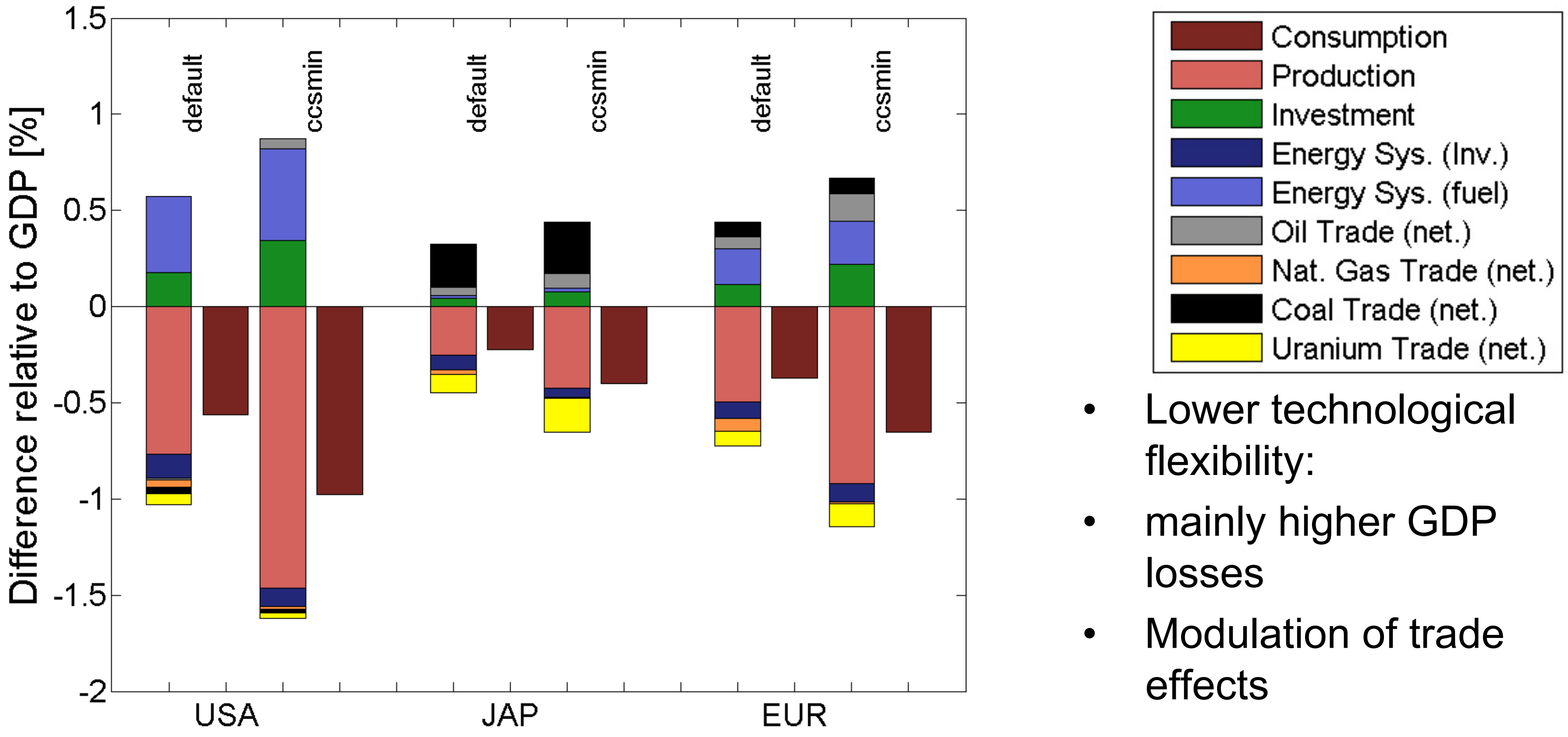
Results: Domestic and Energy Trade Effect



- Domestic effects dominate:
- GDP loss
- Shift from fuel costs to investment costs
- Trade effects:
  More costs for Gas and Uranium imports

Lüken et al. (2009)

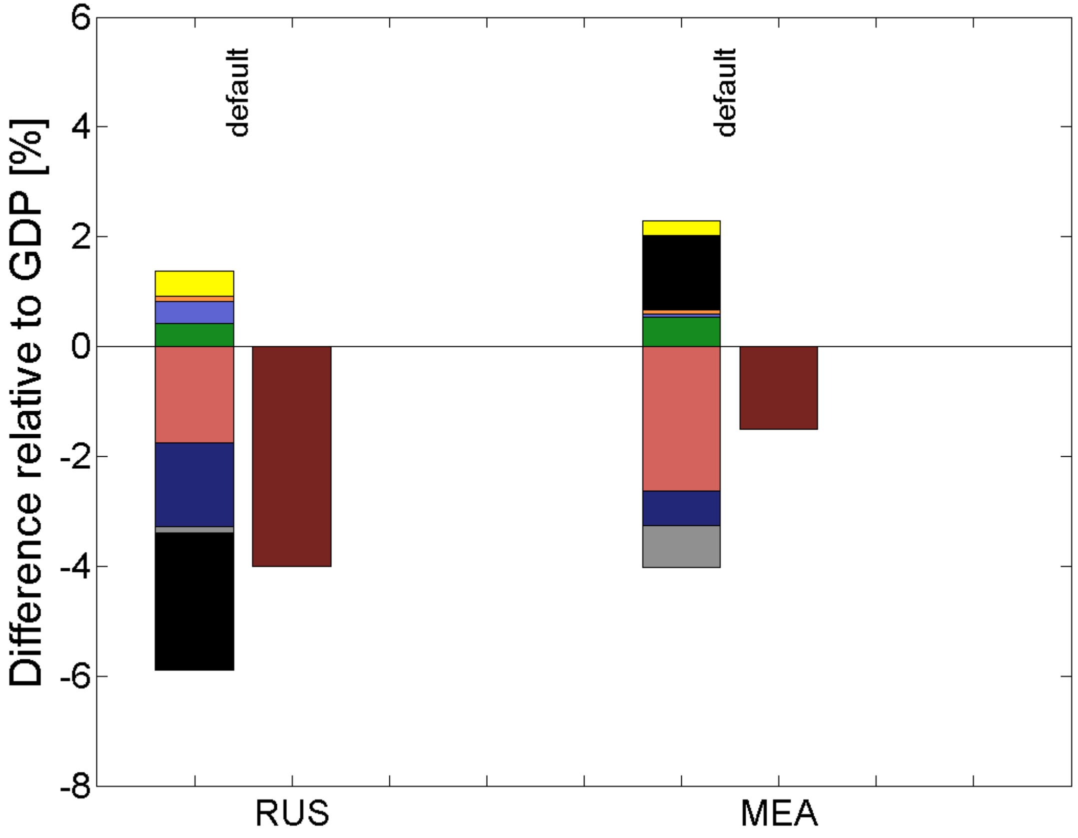
Results: Domestic and Energy Trade Effect



- Lower technological flexibility:
- mainly higher GDP losses
- Modulation of trade effects

Lüken et al. (2009)

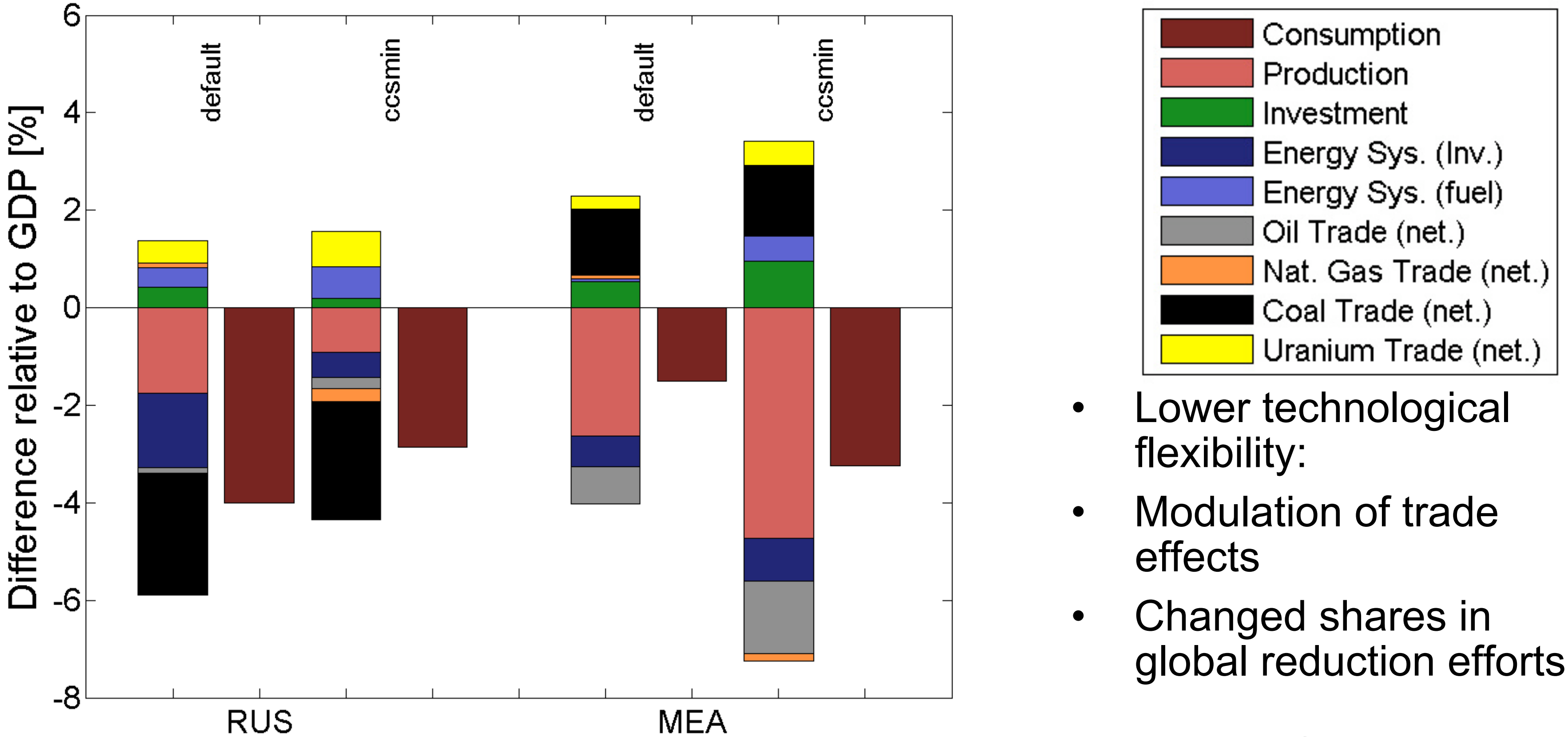
Results: Domestic and Energy Trade Effect



- Stronger trade effects:
- devaluation of Coal and Oil endowments
- revalution of Gas and Uranium endowments

Lüken et al. (2009)

Results: Domestic and Energy Trade Effect

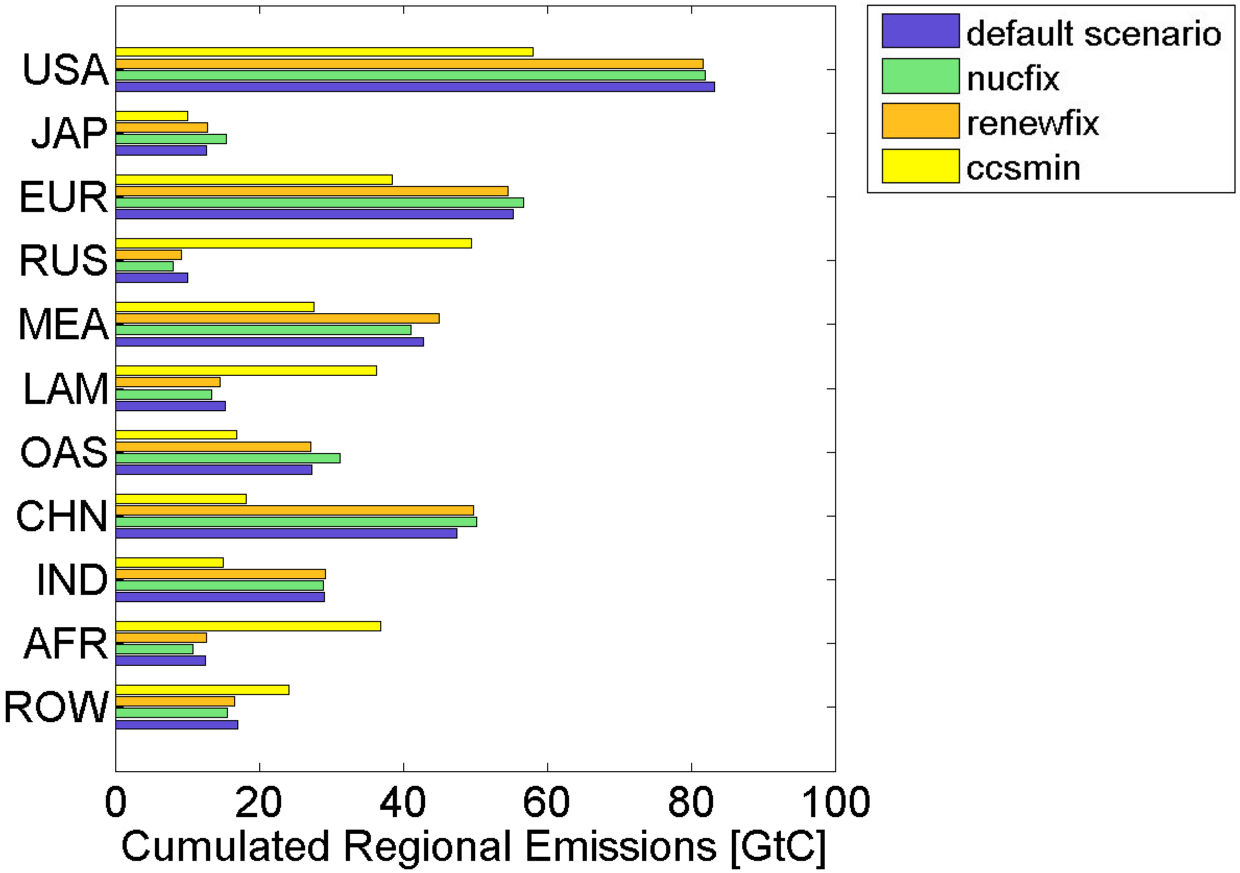


- Lower technological flexibility:
- Modulation of trade effects
- Changed shares in global reduction efforts

e.g.: RUS, ccsmin

Lüken et al. (2009)

Regional Emissions (cumulative)

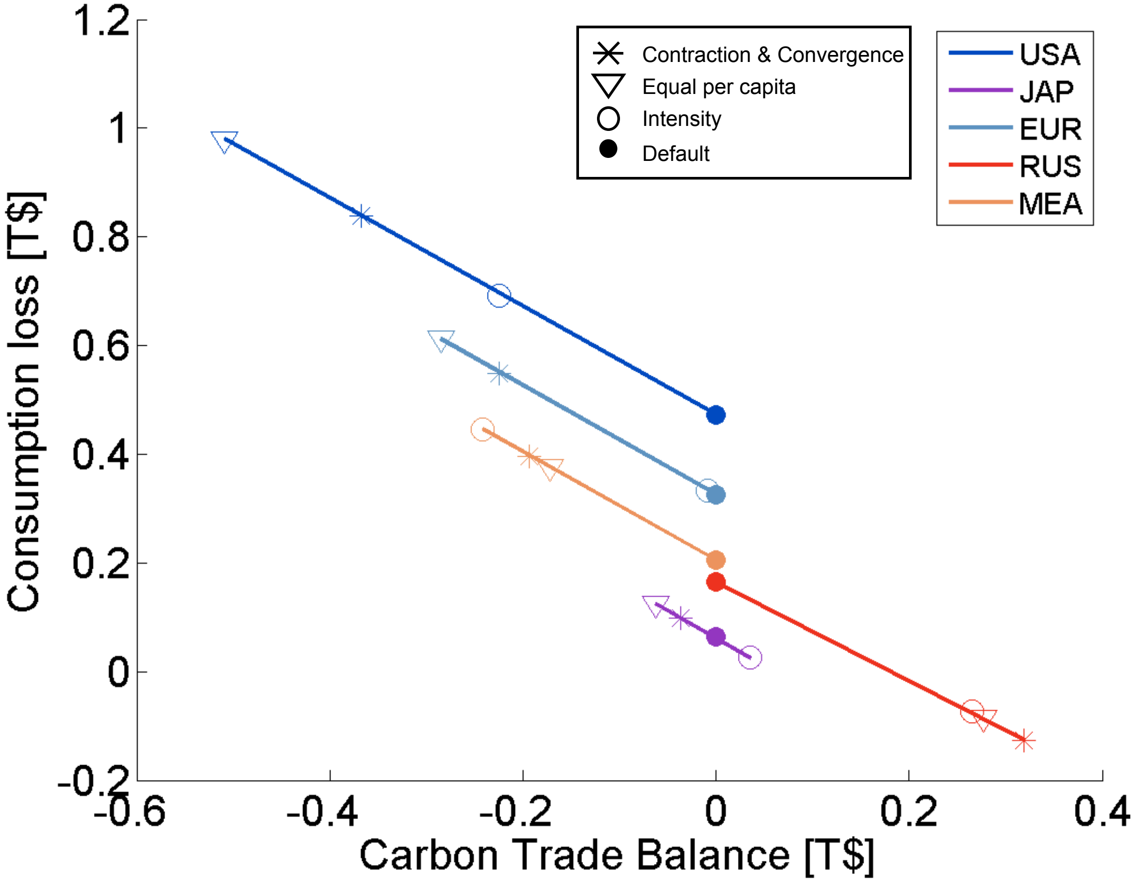


Lüken et al. (2009)

Results: Permit Trade Effect

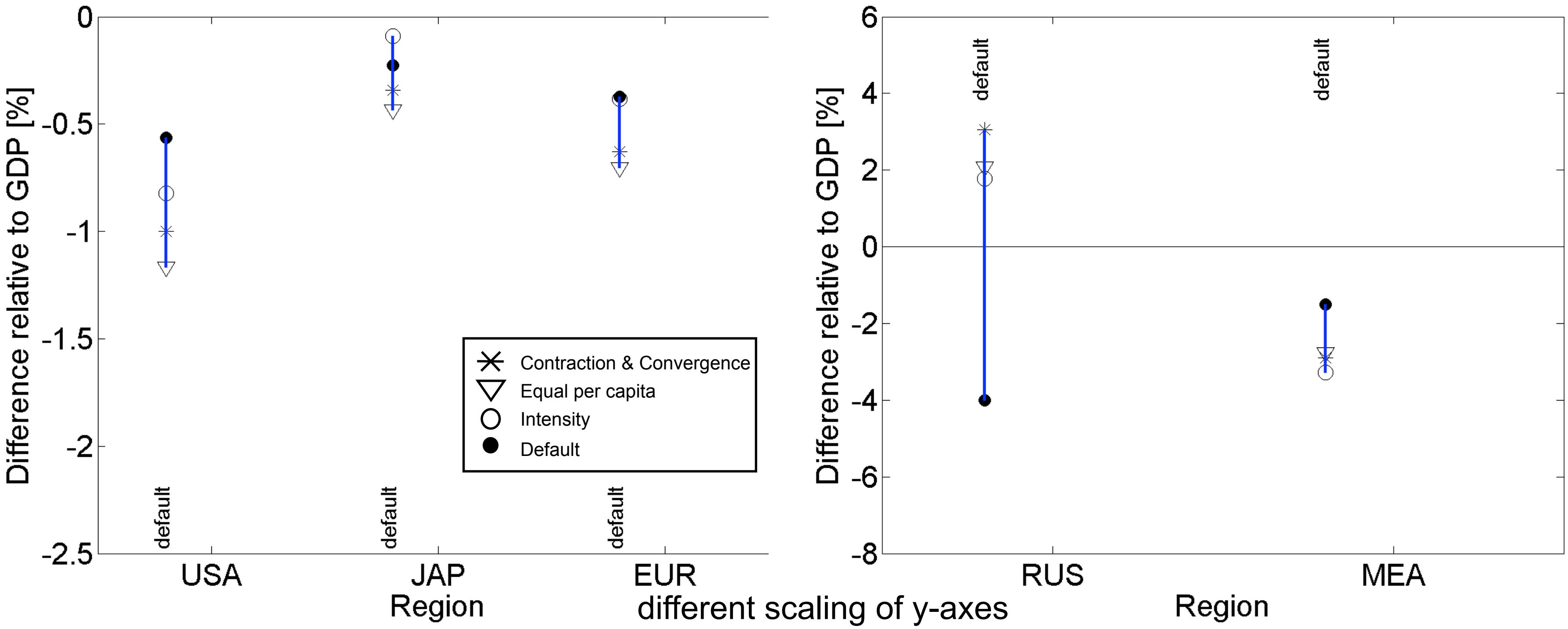
- linear relation
- huge (absolute) numbers

→ Strong redistribution implied by common allocation schemes



Lüken et al. (2009)

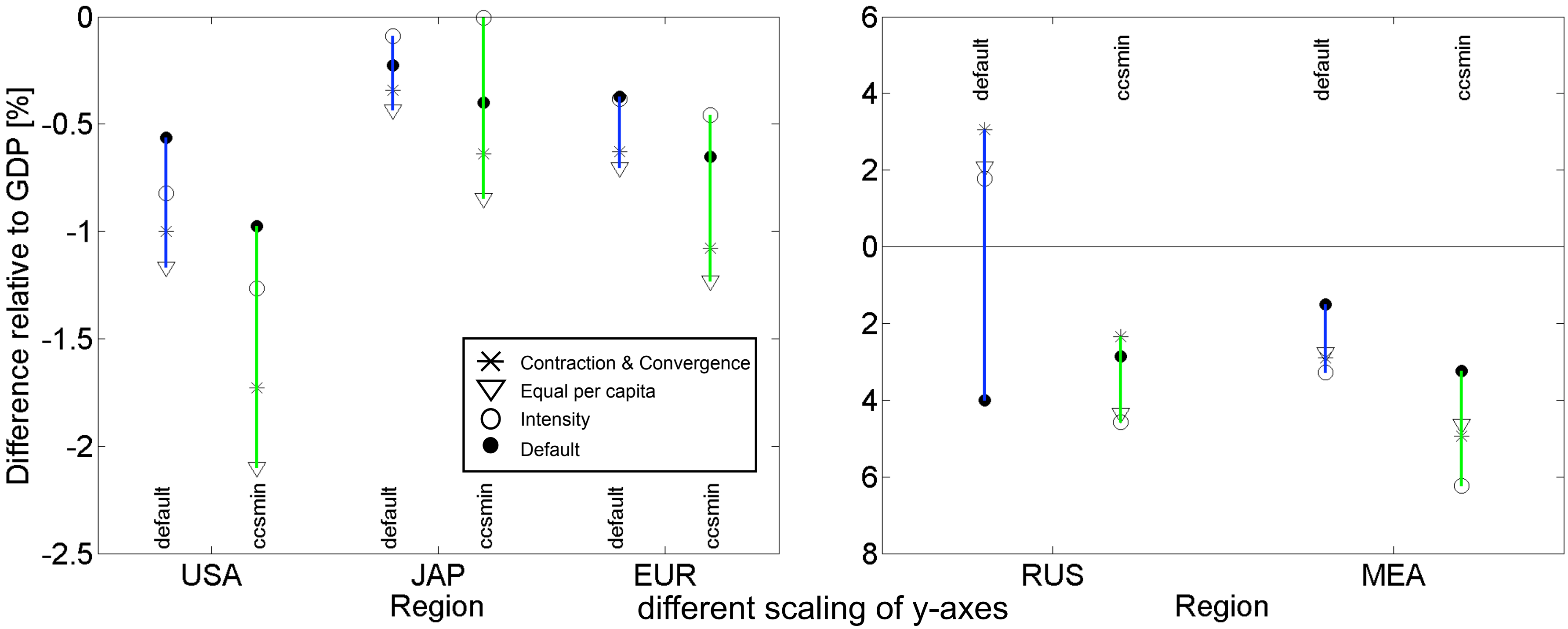
Results: Combined effects



different scaling of y-axes

Lüken et al. (2009)

Results: Combined effects



- Greater impact of allocation scheme, when technological flexibility is lower
- Incentive for industrialized regions to promote technology
- Exceptions (e.g., RUS, ccsmin): lower share in global reduction effort

Lüken et al. (2009)

Rent Income and Technology: Conclusions

- Trade effects matter for the distributive effects of mitigation:
  - Costs of fossil energy exporters can largely be attributed to the devaluation of their endowments
- Assumptions on the availability of low-carbon technologies have a significant impact
  - on regional shares in the global emission reduction effort
  - on revenues from energy and permit trade due to a modified carbon price

Lüken et al. (2009)

Distributive Effekt: Policy Implications

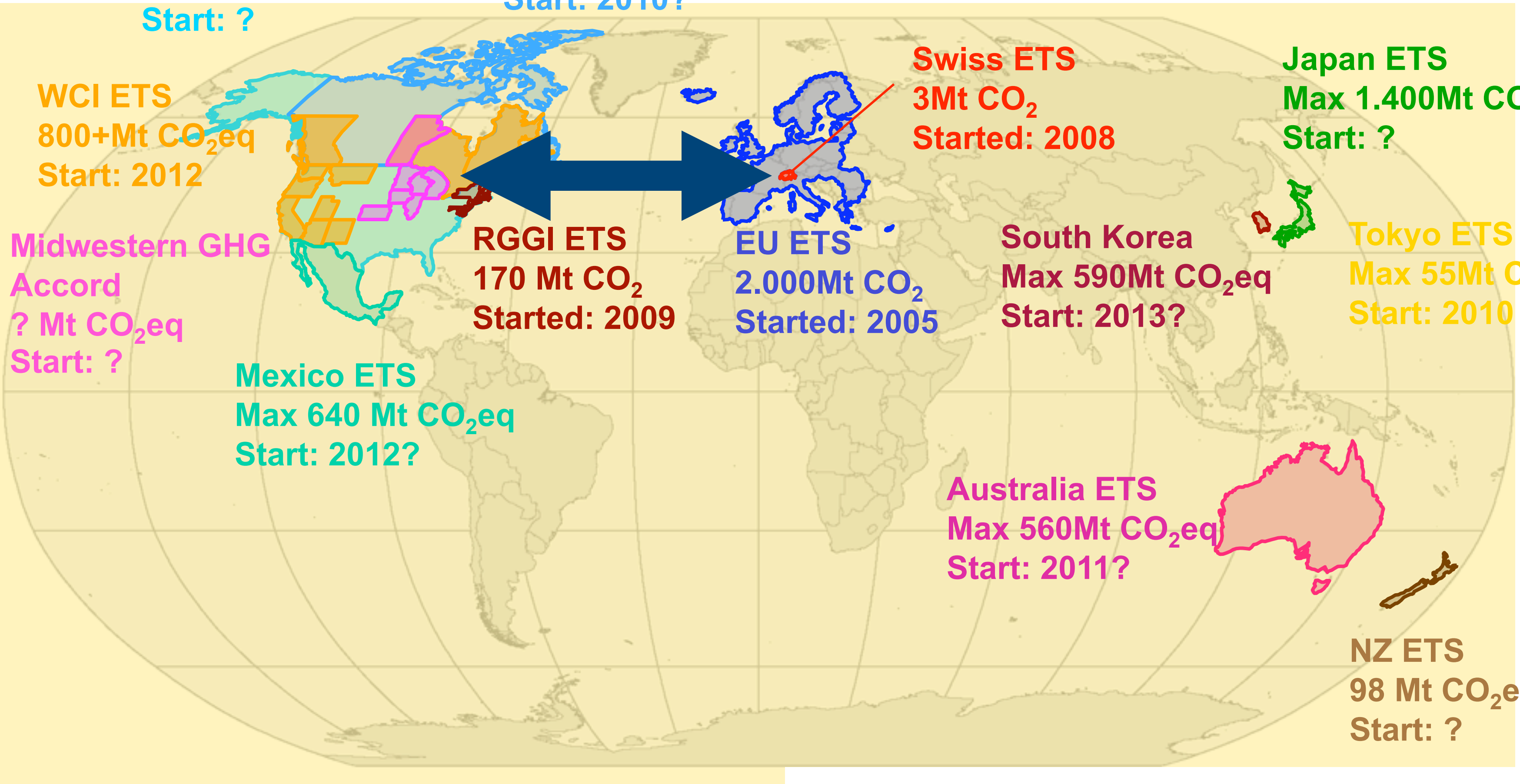
- Higher technological flexibility
  → generally leads to lower redistributions
  → less conflicts about permit allocation scheme

- Incentives for industrialized regions to promote the feasibility of low-carbon technologies, especially under allocation schemes that generate high redistributions

➔ A broad portfolio of low-carbon technologies facilitates international agreements on a permit allocation scheme, which is a cornerstone of a stringent global climate policy.

Lüken et al. (2009)

Domestic Cap and Trade: Linking Emerging CO_2-Markets



US ETS
Max 7.000Mt CO_2eq
Start: ?

Canada ETS
Max 740 Mt CO_2eq
Start: 2010?

WCI ETS
800+Mt CO_2eq
Start: 2012

Midwestern GHG Accord
? Mt CO_2eq
Start: ?

Mexico ETS
Max 640 Mt CO_2eq
Start: 2012?

RGGI ETS
170 Mt CO_2
Started: 2009

EU ETS
2.000Mt CO_2
Started: 2005

Swiss ETS
3Mt CO_2
Started: 2008

South Korea
Max 590Mt CO_2eq
Start: 2013?

Japan ETS
Max 1.400Mt CO_2eq
Start: ?

Tokyo ETS
Max 55Mt CO_2
Start: 2010

Australia ETS
Max 560Mt CO_2eq
Start: 2011?

NZ ETS
98 Mt CO_2eq
Start: ?

“The European Commission is preparing to call on the United States to create a trans-Atlantic system of carbon trading”

- Herald Tribune, Friday, January 23rd, 2009

Source: Flachsland (2009)

Regulating Carbon Markets – **ICAP**

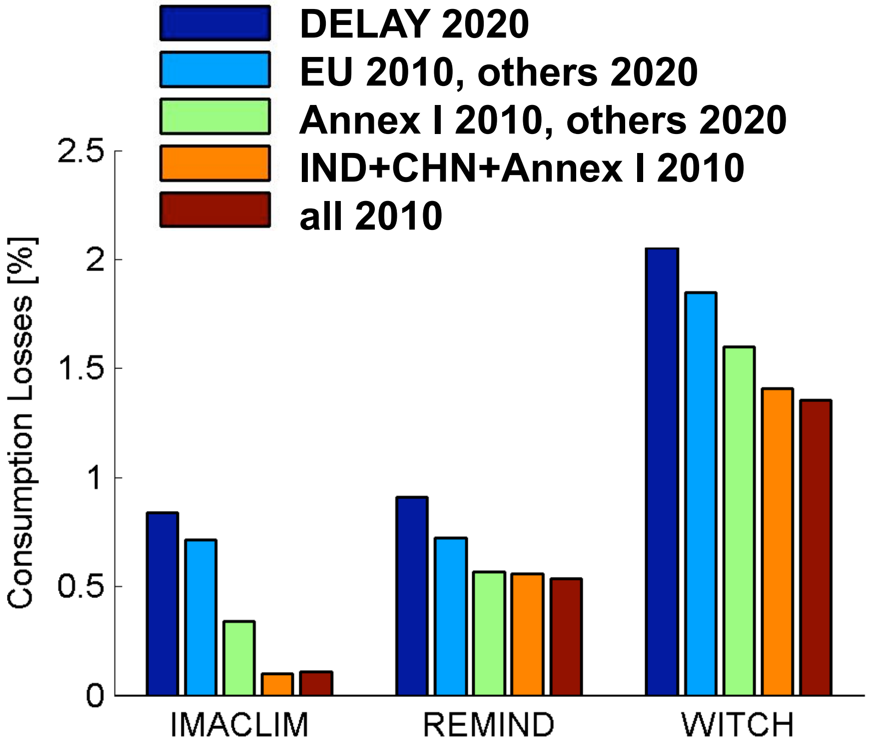
ICAP Political Declaration (2007):

“(…) an expert forum to discuss relevant questions on the design, compatibility and potential linkage of regional carbon markets”

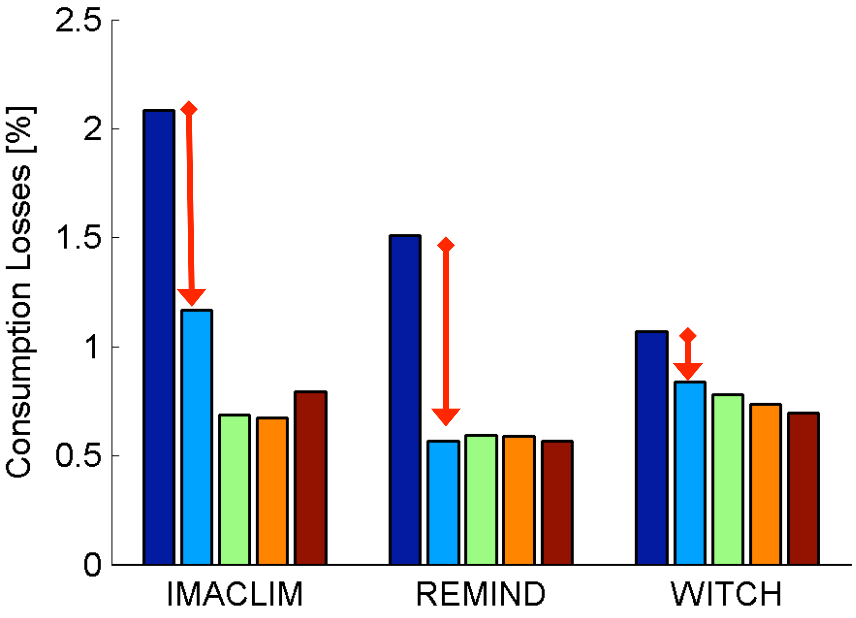
- Public workshops on MRV, auctioning in 2008
- Exchange between regional regulators
- Develop best practice
- Nucleus for international regulatory body alongside UNFCCC?

The Cost of Delay…

…and the case for early action



WORLD



EU-27

Delay of Participation

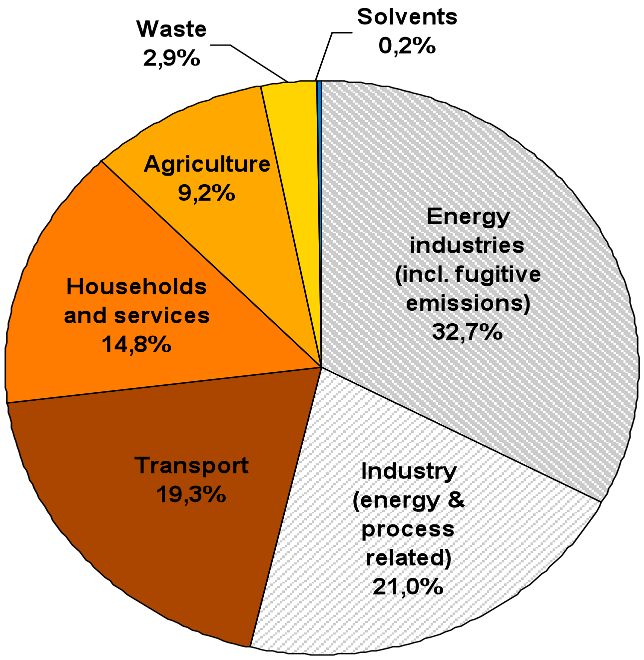
- Incomplete participation increases the global costs of mitigation
- Incomplete participation can increase the long-term costs not just for early entrants but also for late entrants
- Mechanisms to bring international action closer to full participation can decrease costs for all involved
- Clear expectation about future targets lead to near-term reductions in preparation and lower costs for the first mover

Coverage: Broad is Beautiful

- Full sectoral coverage optimal
- Broadening coverage enhances efficiency
- Small sources can be included upstream
- Exclude uncertain / unverifiable sources
- Clear message over long-term development of cap and coverage strengthens investor confidence

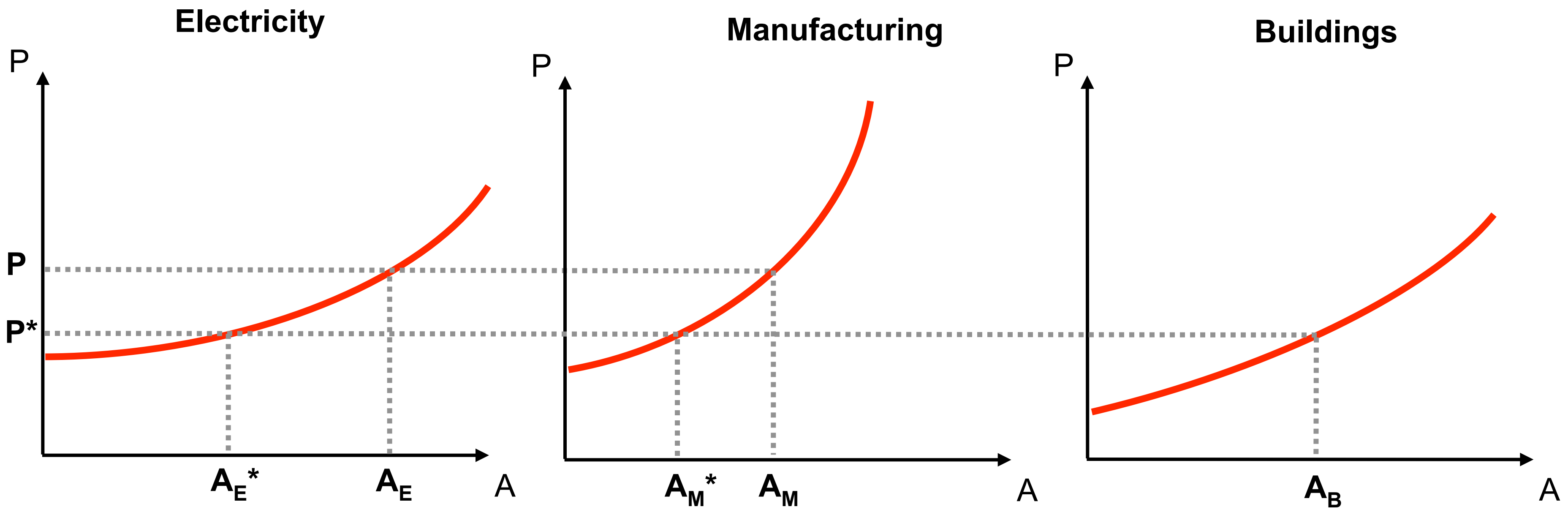
Total EU-27 greenhouse gas emissions by sector, 2006

(Source: European Environment Agency)



EU ETS covers 2.02 GtCO2 or ~40% of total

Broadening Sectoral Coverage Lowers Abatement Costs



Goal: Achieve a given abatement level A

- If coverage is limited to electricity and manufacturing:

$$A = A_E + A_M \;\; \textit{at price } P$$

- If coverage is extended to include buildings:

$$A = A_E^* + A_M^* + A_B \textit{ at } \boldsymbol{\textit{lower price } P^*}$$

Emissions Trading: Allocation of Permits

How to allocate permits to regulated firms:

i) ’grandfathering‘ (=giving away for free)

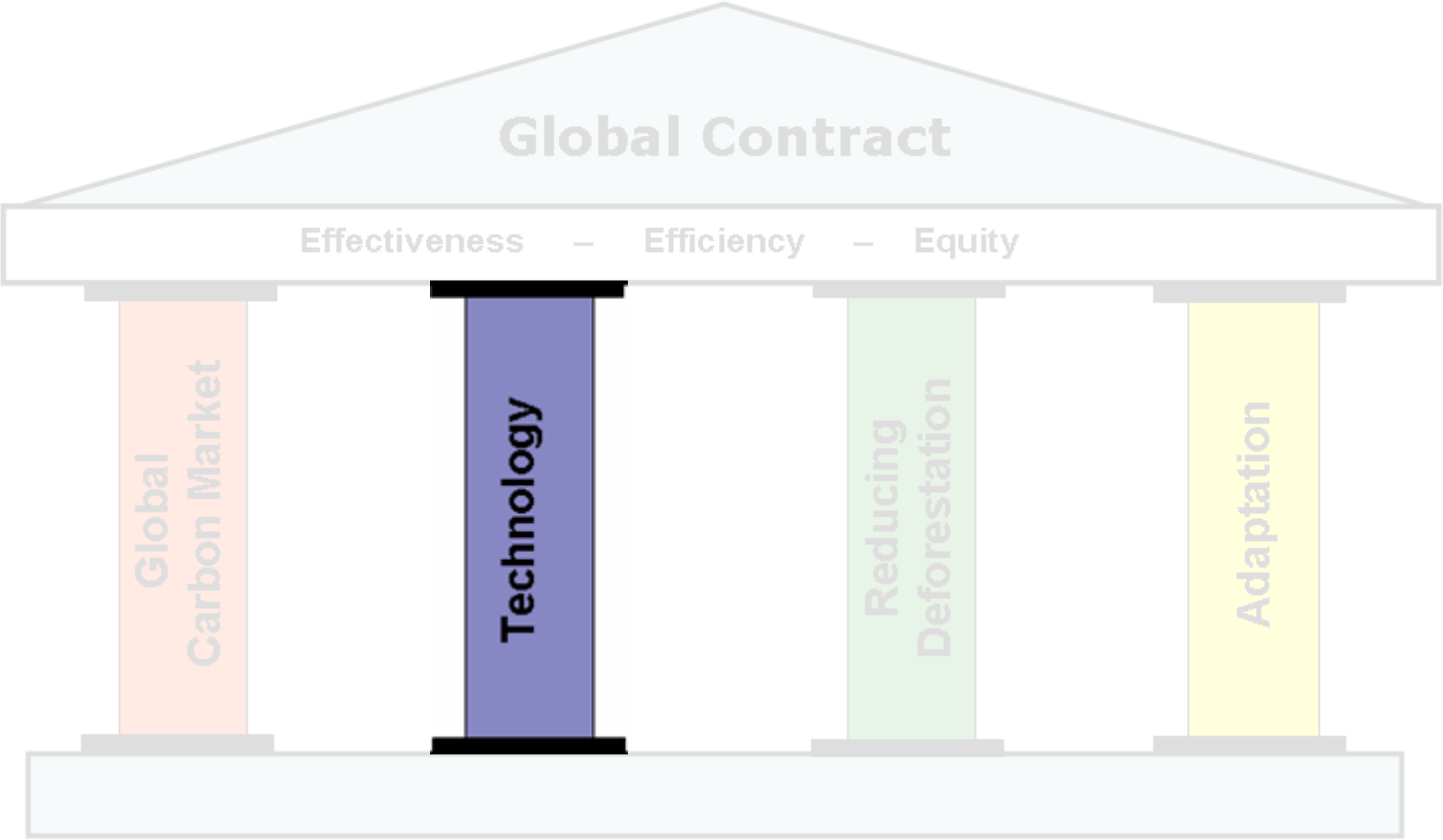
ii) auctioning

iii) mix of both

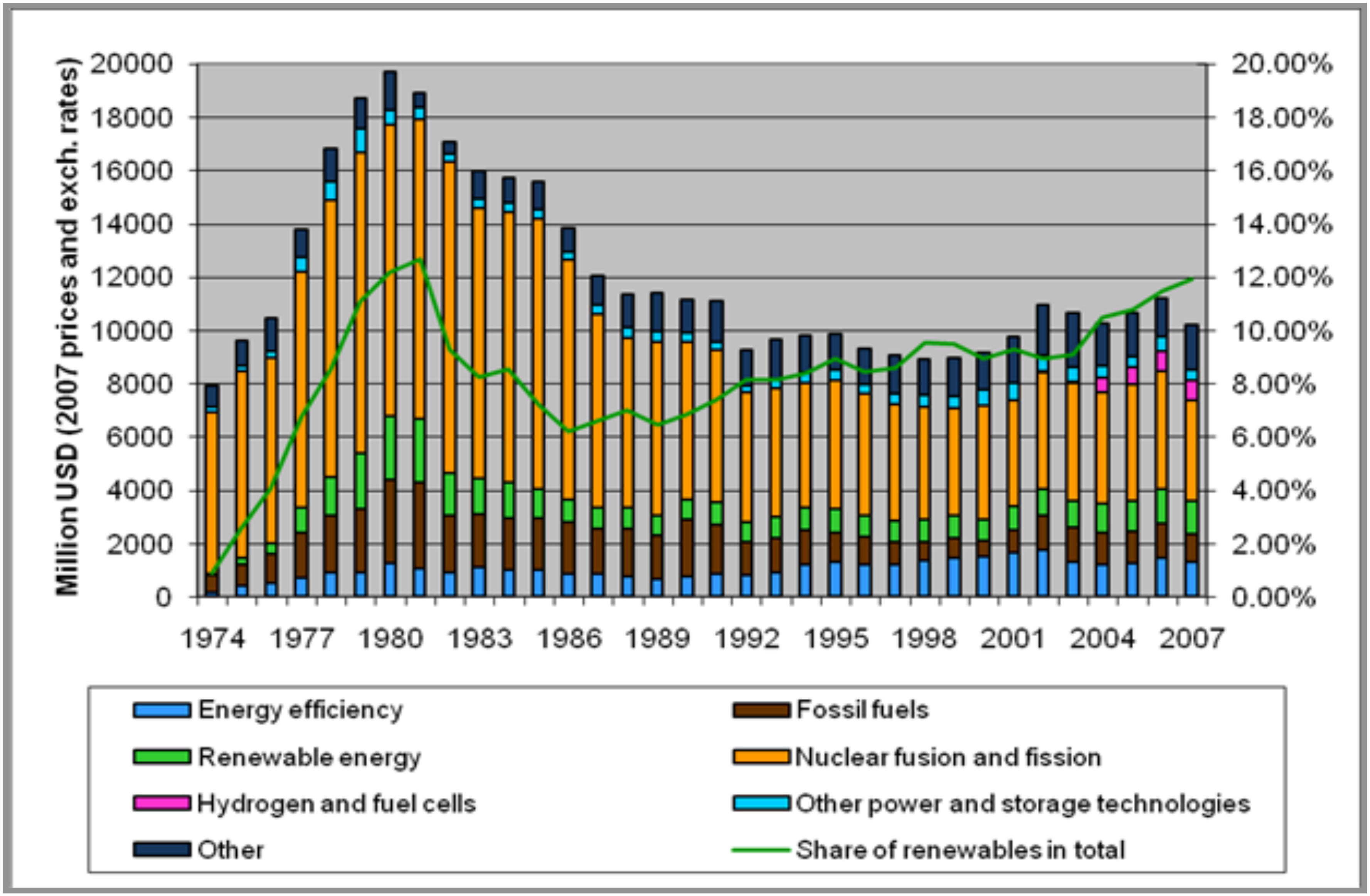
The EU Emissions Trading System – **Reform**

1. Auction allowances!
2. Include all sectors
3. Price carbon where substitution possibilities are the highest up-stream systems are beneficial
4. Include more regions – towards a global carbon market

Architecture of a Global Contract



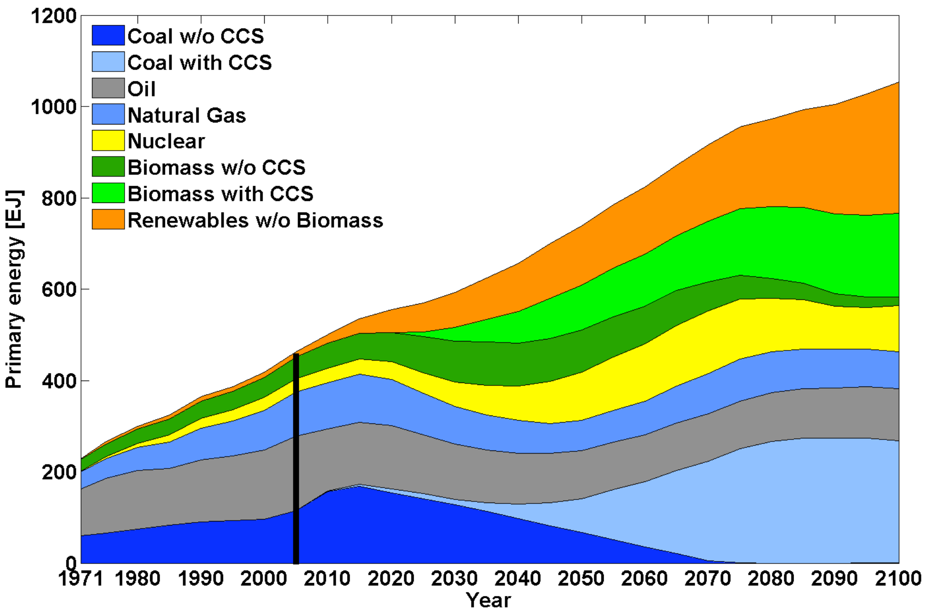
R&D-Investment in Energy Technologies



Source: Updated version of IPCC (2007), AR4

What‘s the Problem?

- Carbon price should provide all necessary incentives:
    - Low-carbon technologies become more profitable
    - Firms will develop technologies to reap these profits
- *Only if*
    - Carbon price is fully credible
    - No other market failures exist
- See, for example, results from REMIND-R



Source: REMIND-R, ADAM 450ppm-eq, 4/6/2009, Steckel/Knopf

What‘s the Problem? (2)

- Carbon pricing alone will not be sufficient to reduce emissions on the scale and pace required as:
  - Future pricing policies of governments and international agreements cannot be 100% **credible**
  - The **uncertainties** and risks both of climate change and the development and deployment of the technologies to address it are of such scale and urgency that the economics of risk points to policies to support the development and use of a portfolio of low-carbon technology options
  - The **positive externalities** of efforts to develop them will be appreciable and the time periods and uncertainties are such that there can be major difficulties in financing through capital markets

Source: Stern (2007)

What to Do?

- Governments can help to foster changes in industry and the research community through a range of instruments:
  - Carbon pricing, through carbon taxes, tradable carbon permits, carbon contracts and/or implicitly through regulation will itself directly support the research for new ways to reduce emissions
  - Raising the level of support for R&D and demonstration projects, both in public research institutions and the private sector
  - Support for early stage commercialisation investments in some sectors

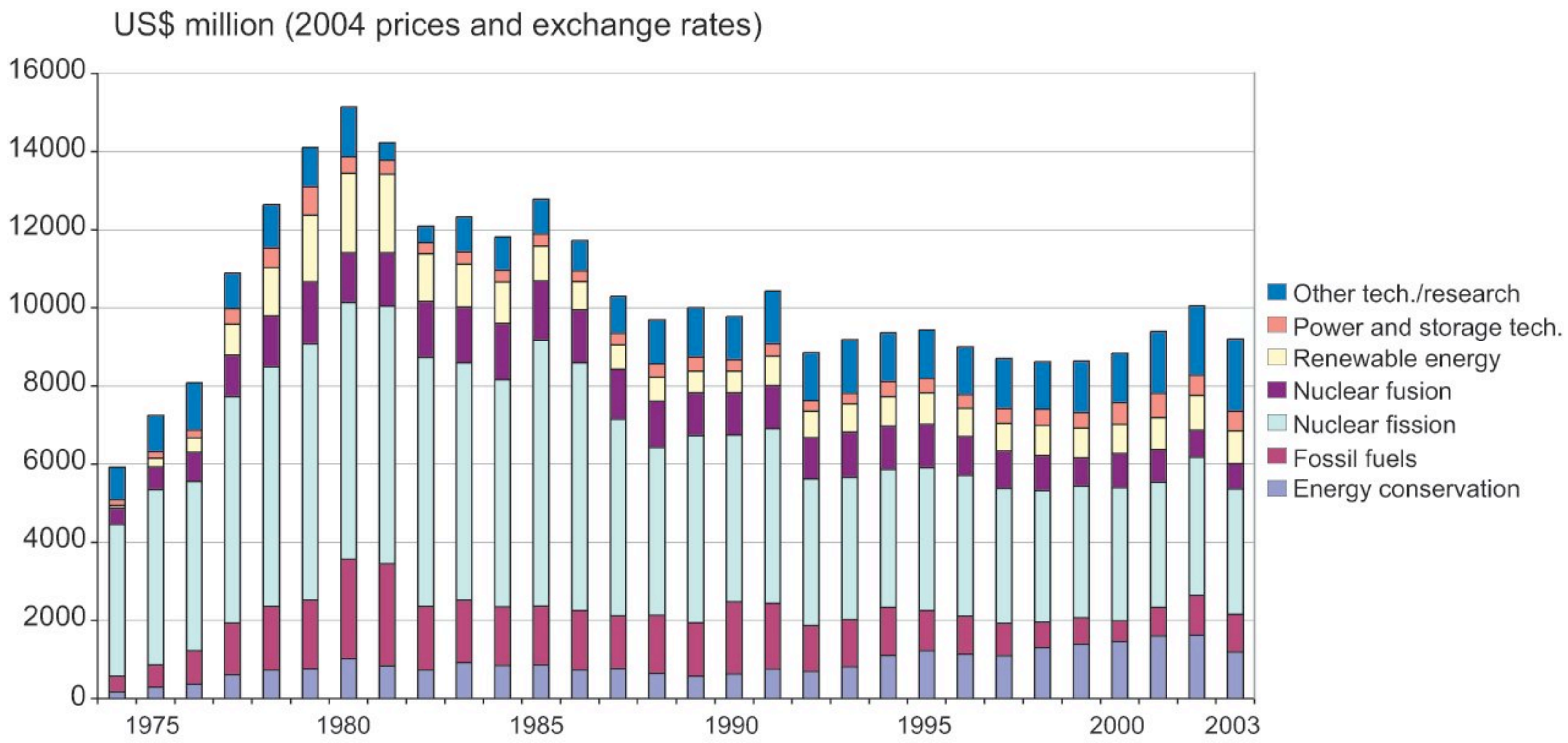
Technology R&D Expenditures

- Oil price shocks of the 1970s boosted technology R&D
- But: There is no evidence yet of a similar response from the latest price surges
- A technology R&D response to the challenge of climate mitigation has not occurred. Energy technology R&D has remained roughly constant over the last 15 years despite the fact that climate change has become a focus of international policy development
- Energy technology R&D is one policy lever that governments have for encouraging a more climate friendly capital, a strengthened publicly funded commitment to technology development could play an important role in altering the trends in GHG emissions

Source: IPCC AR4, Ch1

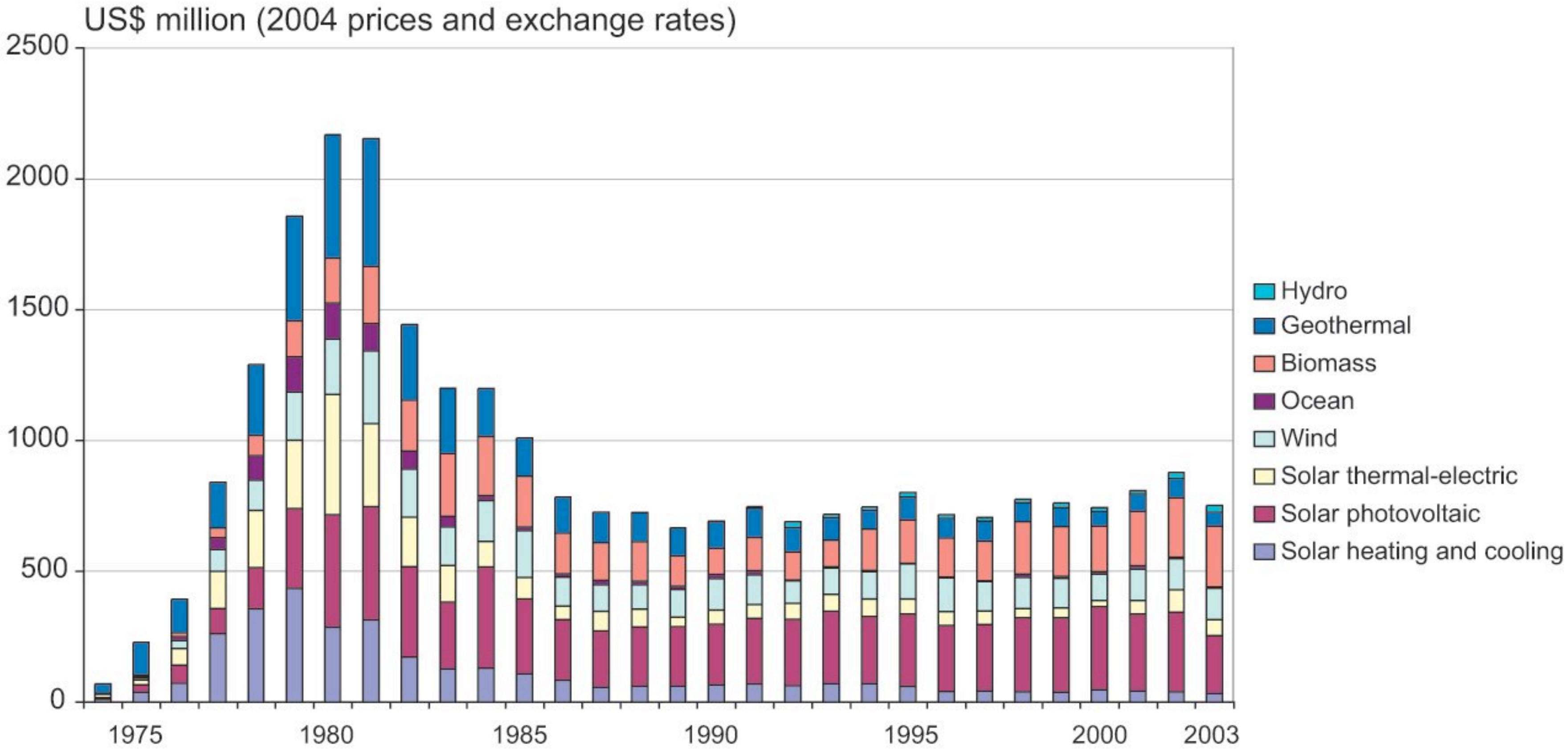
Public Funded R&D Expenditures for Energy

- Declining energy R&D investments: Energy in general

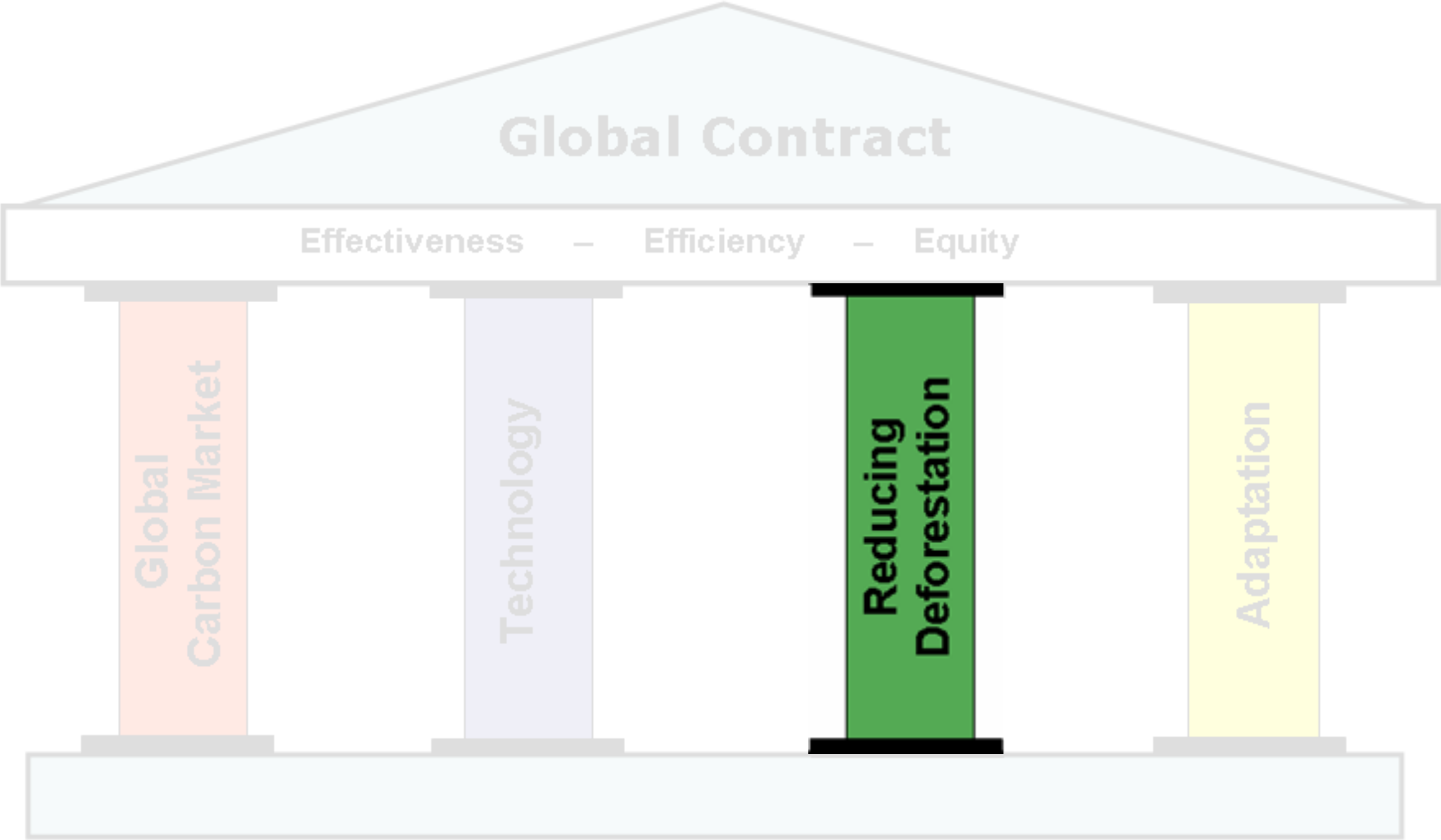


Public Funded R&D Expenditures for Renewable Energy

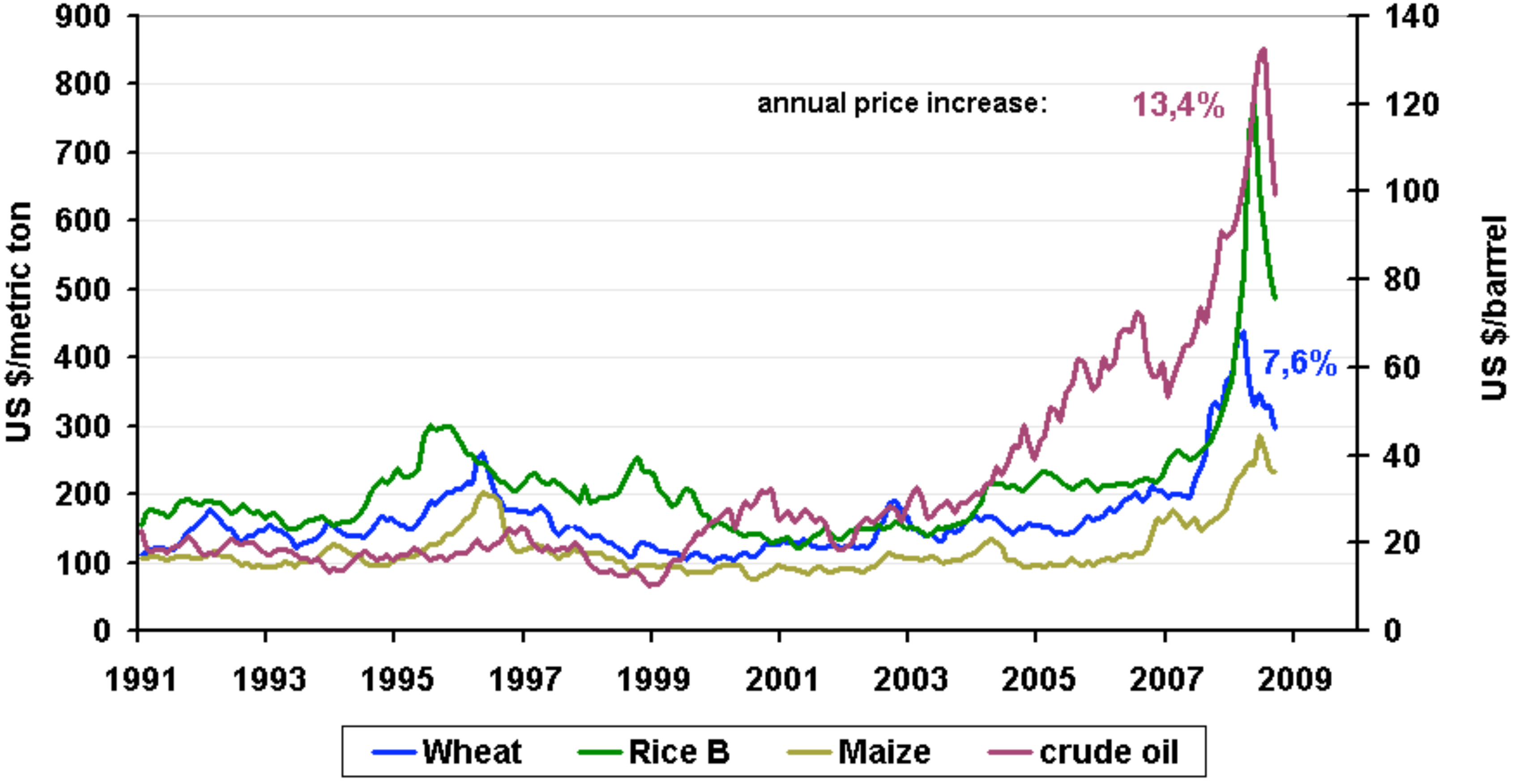
- Declining energy R&D investments: Renewable energy



Architecture of a Global Contract



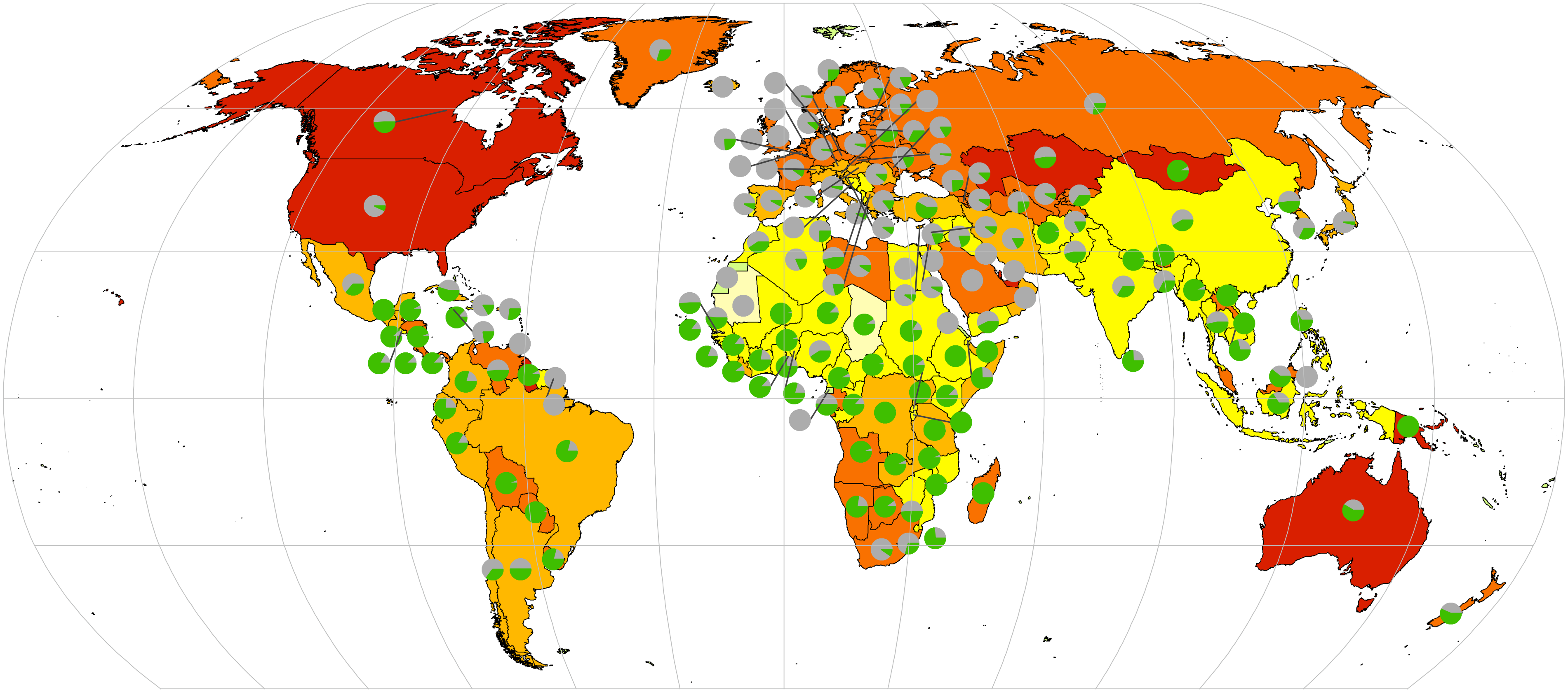
Market Prices for staple foods and crude oil monthly averages 1991 - 2008



Source: IMF; FAO International Commodity Prices

Reducing Deforestation: Fossil vs. LUCF CO_2 Emissions

CO_2 emissions per person and year, 1950 - 2003



CO_2 emissions from fossil fuel combustion and cement production, and including land use change (kg C per person and year from 1950 - 2003)

🟩	-1000 - 0	🟧	1000 - 2000
🟨	0 - 100	🟧	2000 - 5000
🟨	100 - 1000	🟥	5000 - 15000

Ratio ◐
- Emissions per year from fossil fuel combustion and cement production
- Emissions per year from land use change

Avoiding Deforestation

A mechanism for Avoided Deforestation has to:

- **Ensure additionality, permanence & co-benefits**
- **Avoid leakage**
- **Guarantee fair sharing of benefits and costs**

Political framework and design options:

Until now there are no incentives for avoiding tropical deforestation

1) **Carbon market integration**
2) **Fund-based schemes**
3) **Hybrid schemes**

Avoiding Deforestation

Mitigation costs of avoided deforestation

Accounting (bottom-up) (e. g. Grieg-Gran 2007)

50% reduction in deforestation → \$5-10 billion yr^{-1}

Forest models (top-down) (e. g. Kindermann et al. 2008)

10% reduction in deforestation → \$0.4-1.7 billion yr^{-1}

50% reduction in deforestation → \$17.2-28.0 billion yr^{-1}

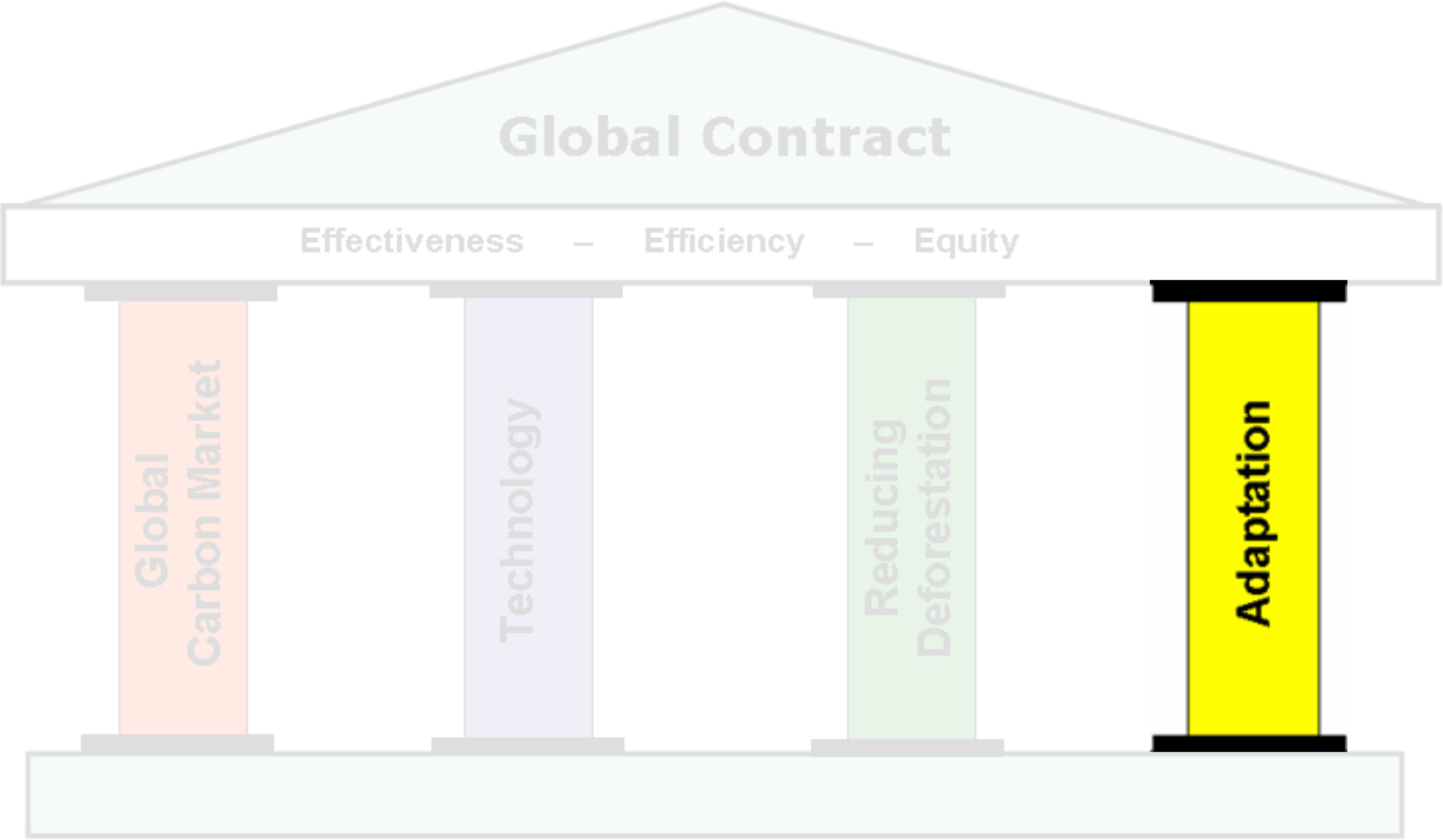
Carbon price (2030) necessary to generate

10% reduction in deforestation: 3.17 \$ t^{-1} CO_2

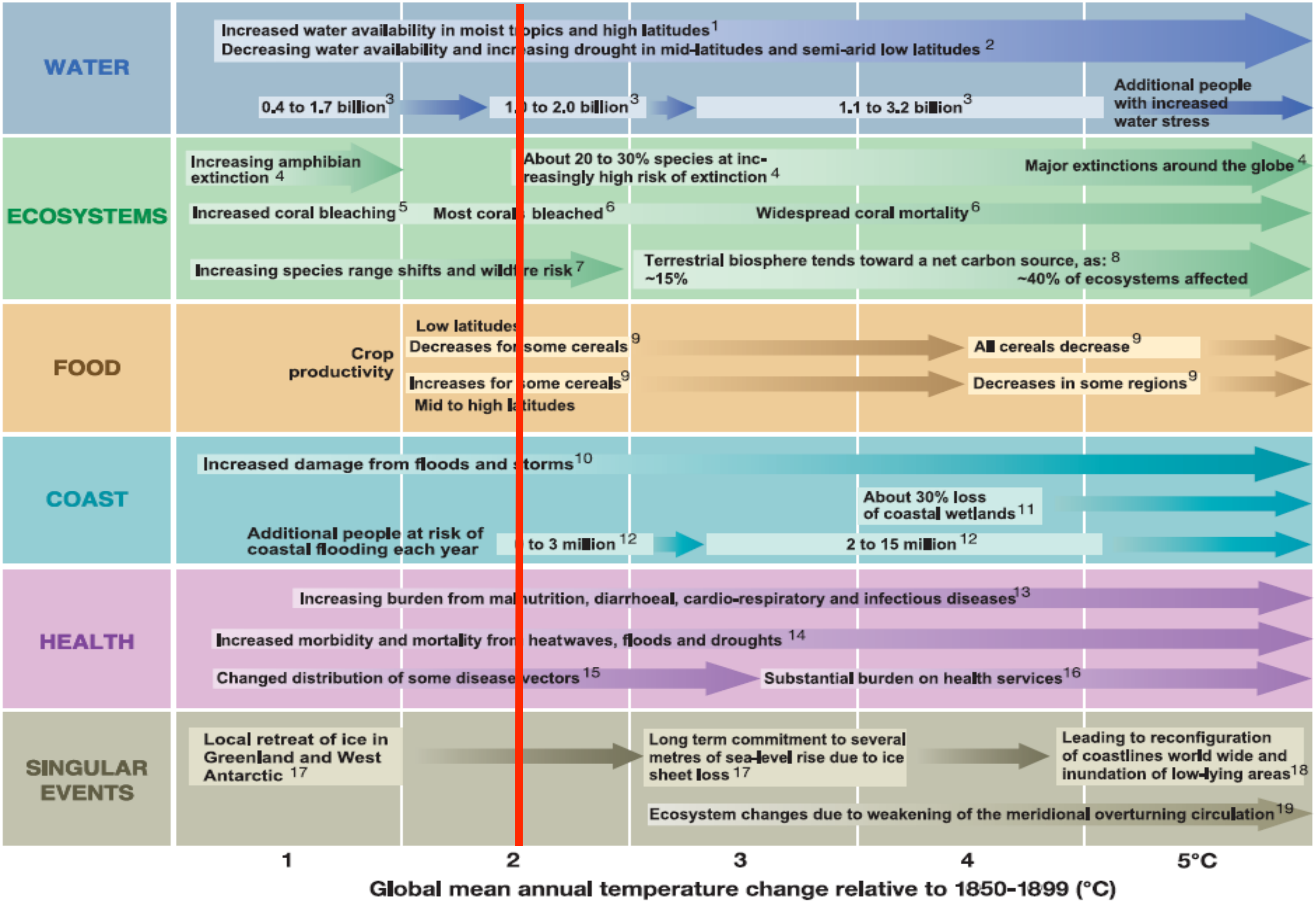
50% reduction in deforestation: 15.58 \$ t^{-1} CO_2

(Source: Kindermann et al. 2008)

Architecture of a Global Contract



Mitigation and Adaptation



WATER

Increased water availability in moist tropics and high latitudes[1]

Decreasing water availability and increasing drought in mid-latitudes and semi-arid low latitudes [2]

0.4 to 1.7 billion[3]

1.0 to 2.0 billion[3]

1.1 to 3.2 billion[3]

Additional people with increased water stress

ECOSYSTEMS

Increasing amphibian extinction [4]

About 20 to 30% species at increasingly high risk of extinction [4]

Major extinctions around the globe [4]

Increased coral bleaching [5]

Most corals bleached [6]

Widespread coral mortality [6]

Increasing species range shifts and wildfire risk [7]

Terrestrial biosphere tends toward a net carbon source, as: [8]
~15%
~40% of ecosystems affected

FOOD

Crop productivity

Low latitudes

Decreases for some cereals [9]

All cereals decrease [9]

Increases for some cereals[9]

Decreases in some regions[9]

Mid to high latitudes

COAST

Increased damage from floods and storms [10]

About 30% loss of coastal wetlands [11]

Additional people at risk of coastal flooding each year

0 to 3 million [12]

2 to 15 million [12]

HEALTH

Increasing burden from malnutrition, diarrhoeal, cardio-respiratory and infectious diseases[13]

Increased morbidity and mortality from heatwaves, floods and droughts [14]

Changed distribution of some disease vectors [15]

Substantial burden on health services[16]

SINGULAR EVENTS

Local retreat of ice in Greenland and West Antarctic [17]

Long term commitment to several metres of sea-level rise due to ice sheet loss [17]

Leading to reconfiguration of coastlines world wide and inundation of low-lying areas[18]

Ecosystem changes due to weakening of the meridional overturning circulation[19]

Architecture of a Global Contract