POTSDAM INSTITUTE FOR CLIMATE IMPACT RESEARCH

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The Economics of Atmospheric Stabilization

Santa Fe, 23th July 2009

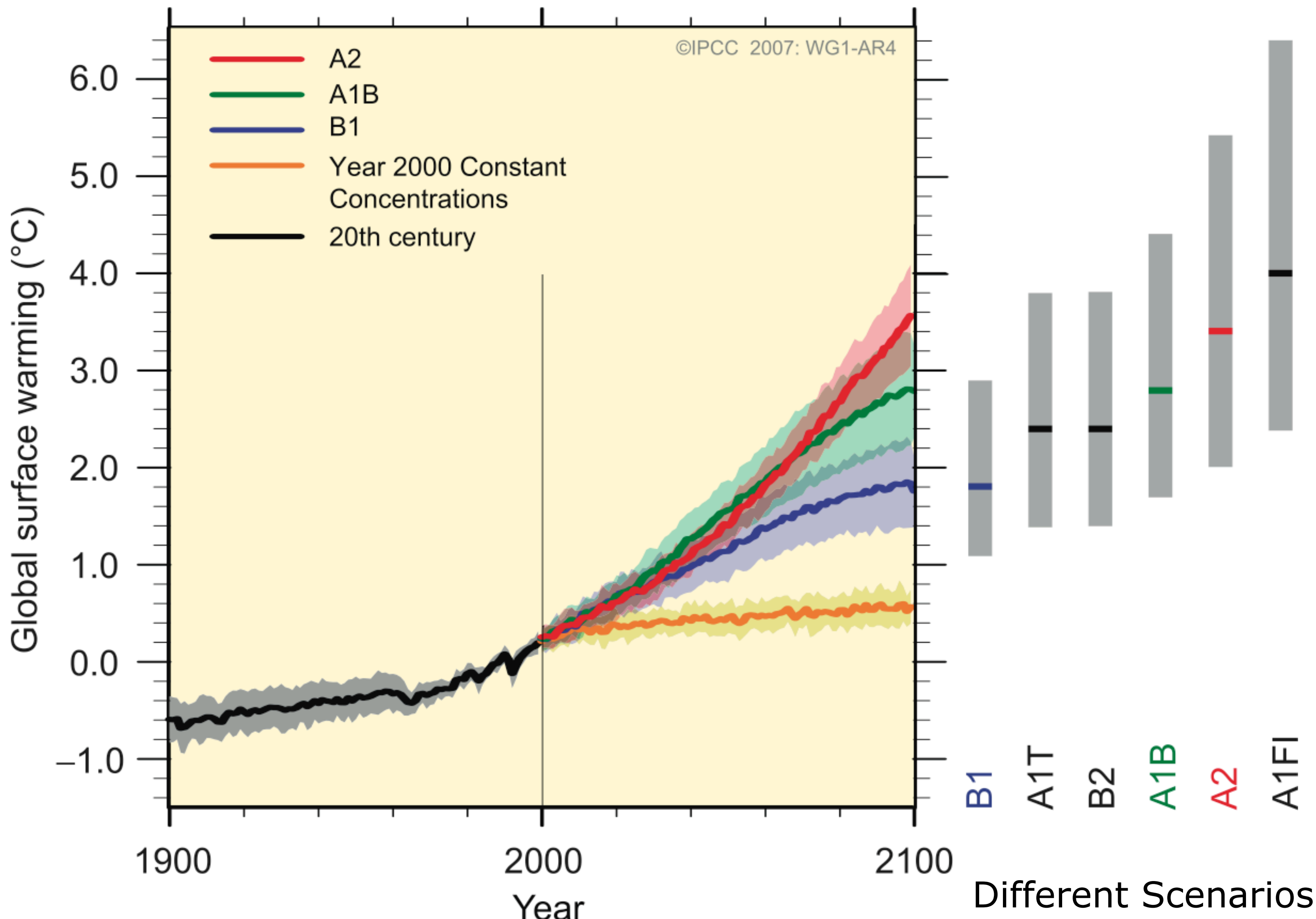
Summer School on Global Sustainability 2009

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

WMO Working Group III Mitigation of Climate Change UNEP

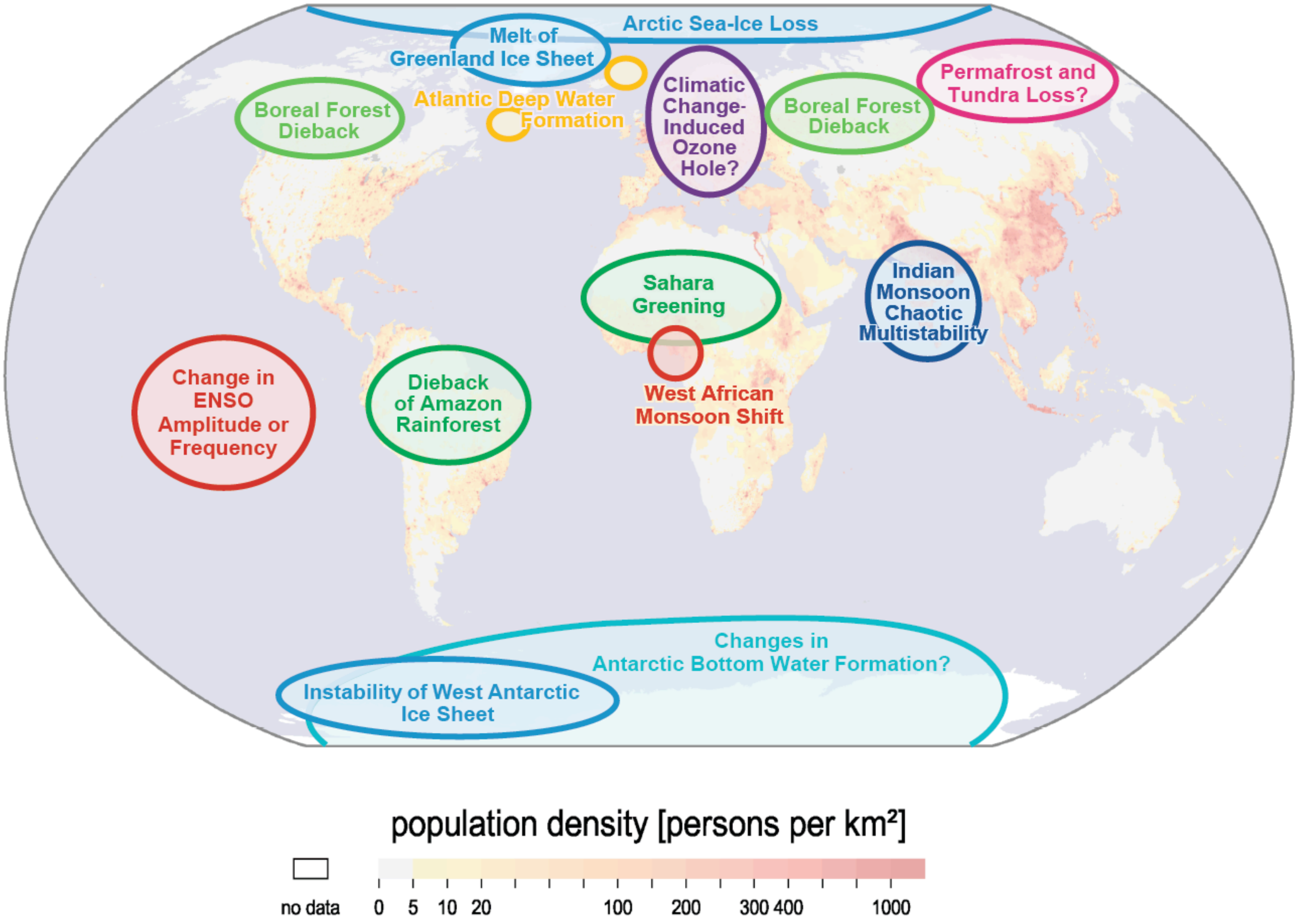
Technische Universität Berlin

Projections of Global Mean Temperature



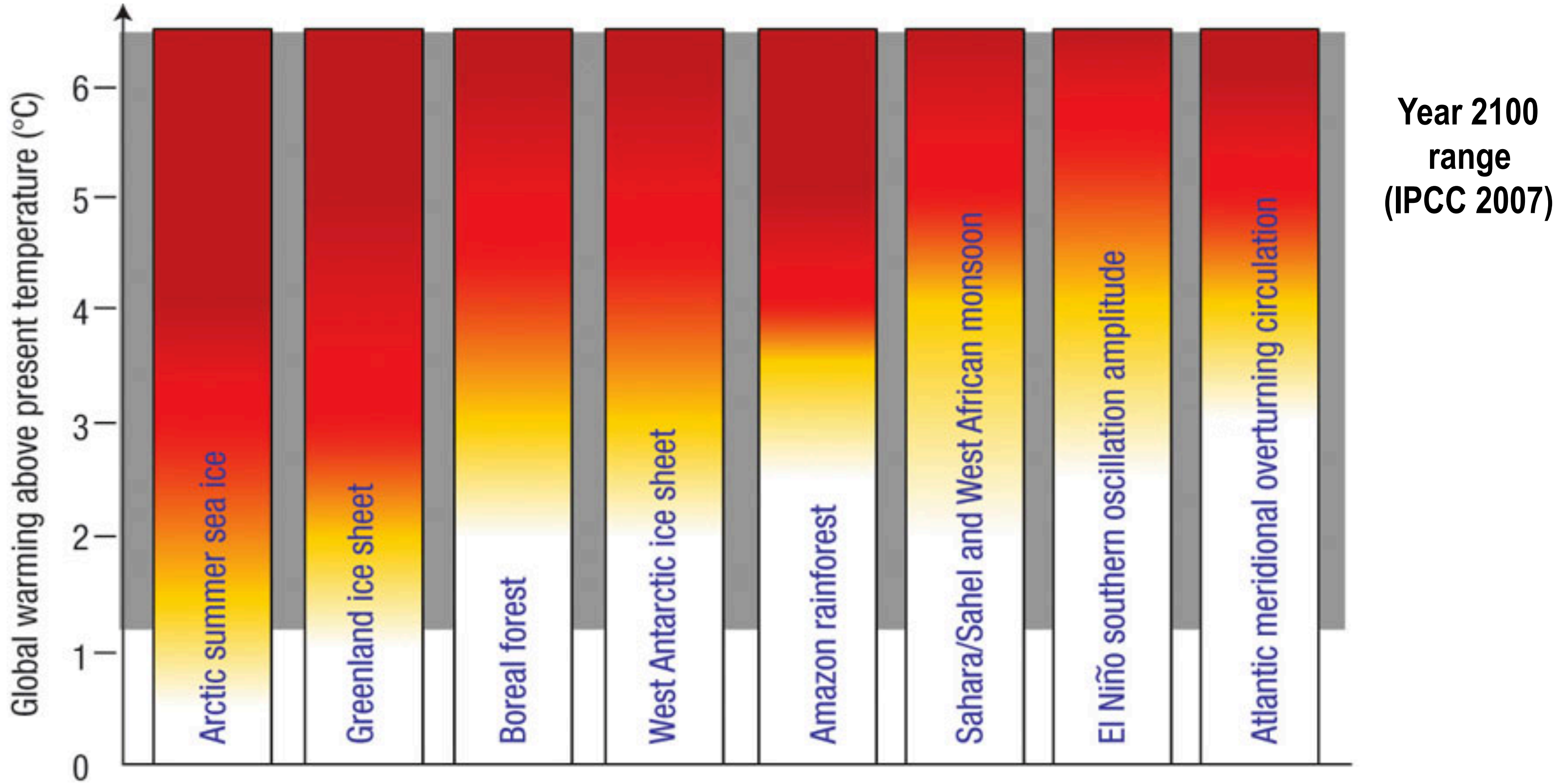
IPCC 2007

Tipping Points in the Earth System



T. M. Lenton & H. J. Schellnhuber (Nature Reports Climate Change, 2007)

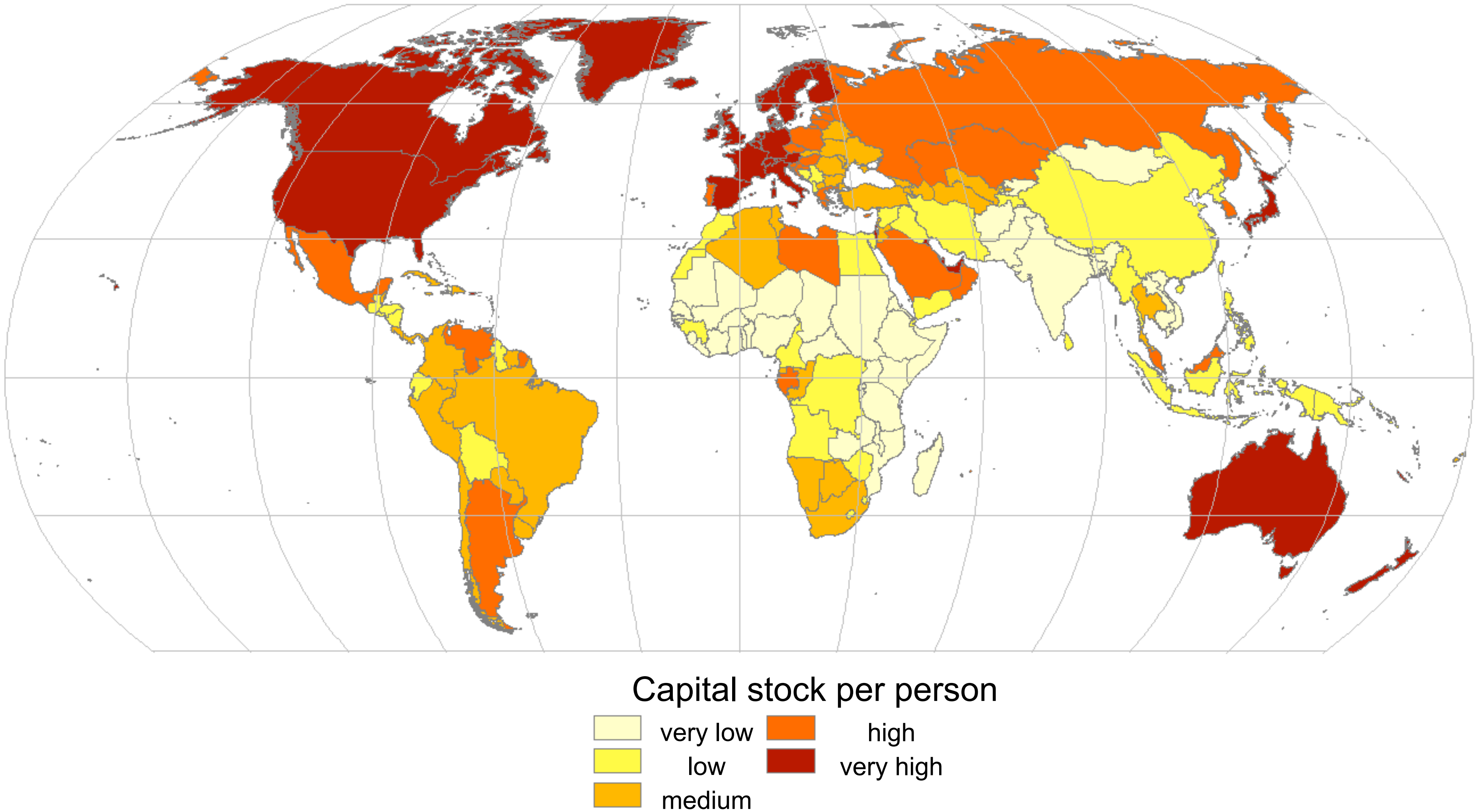
Burning Embers



Potential policy-relevant tipping elements that could be triggered by global warming this century, with shading indicating their uncertain thresholds. For each threshold, the transition from white to yellow indicates a lower bound on its proximity, and the transition from yellow to red, an upper bound. The degree of uncertainty is represented by the spread of the colour transition.

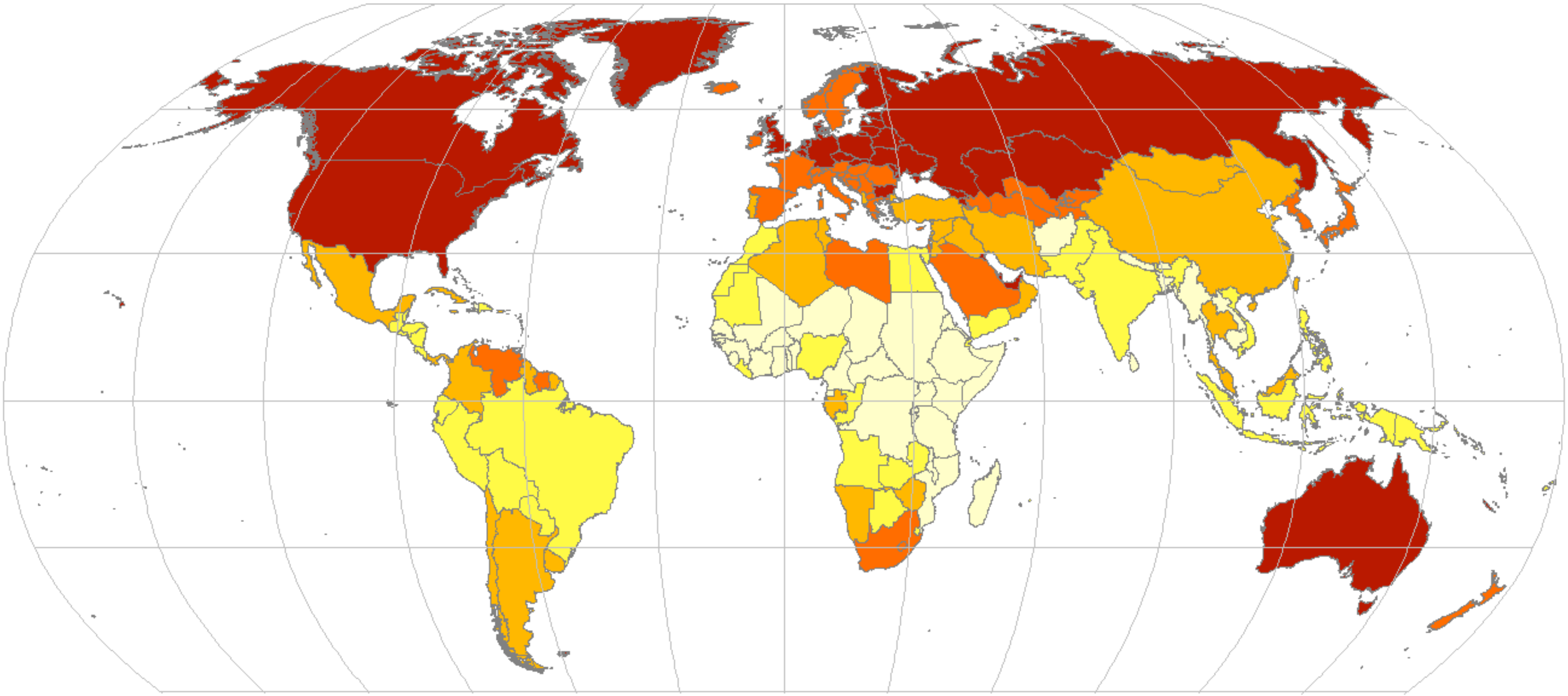
T. M. Lenton & H. J. Schellnhuber (Nature Reports Climate Change, 2007)

World Map of Wealth



Source: Füssel (2007)

World Map of Carbon Debt

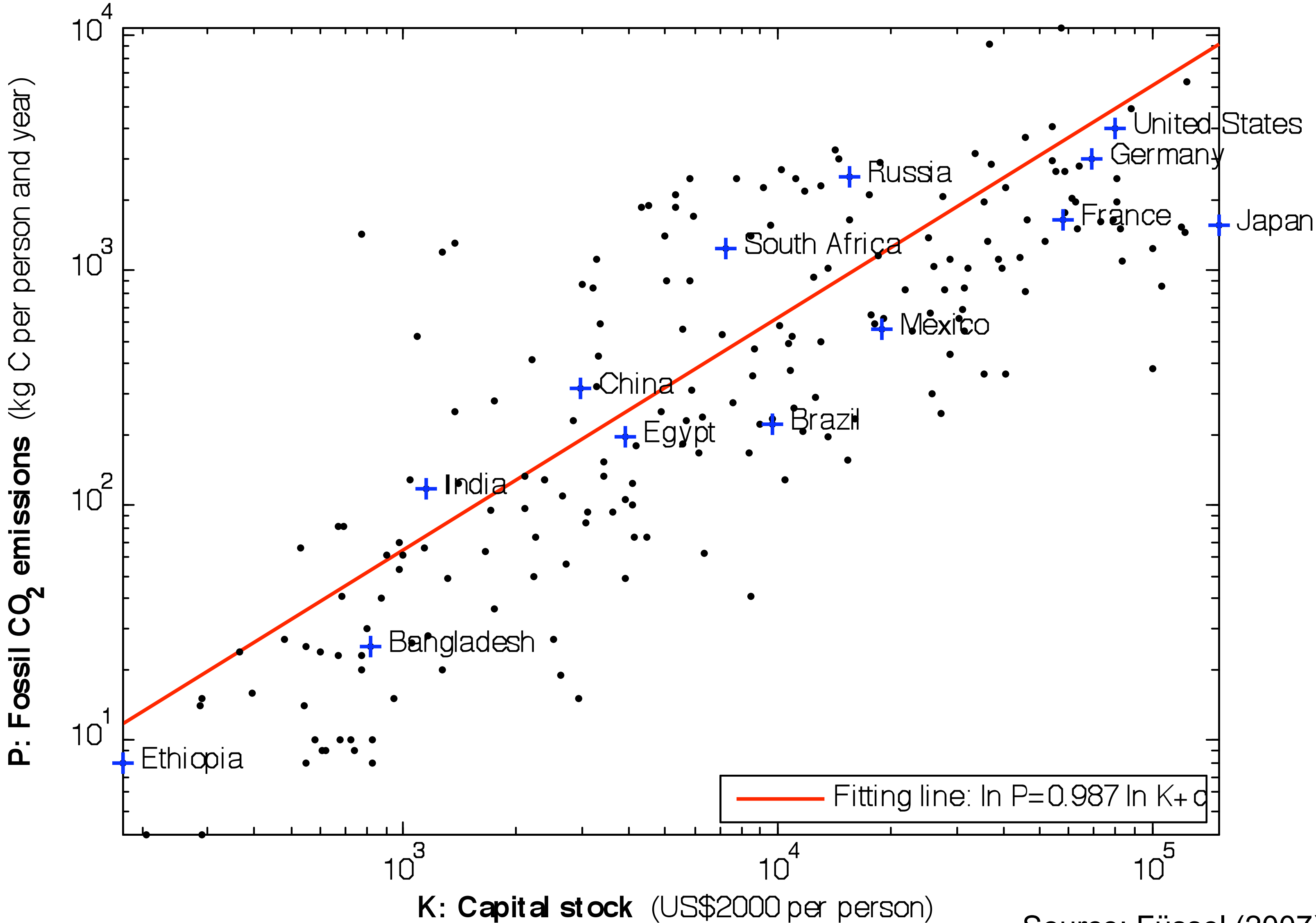


Carbon emissions per person from fossil fuel burning (1950-2003)

very low
low
medium
high
very high

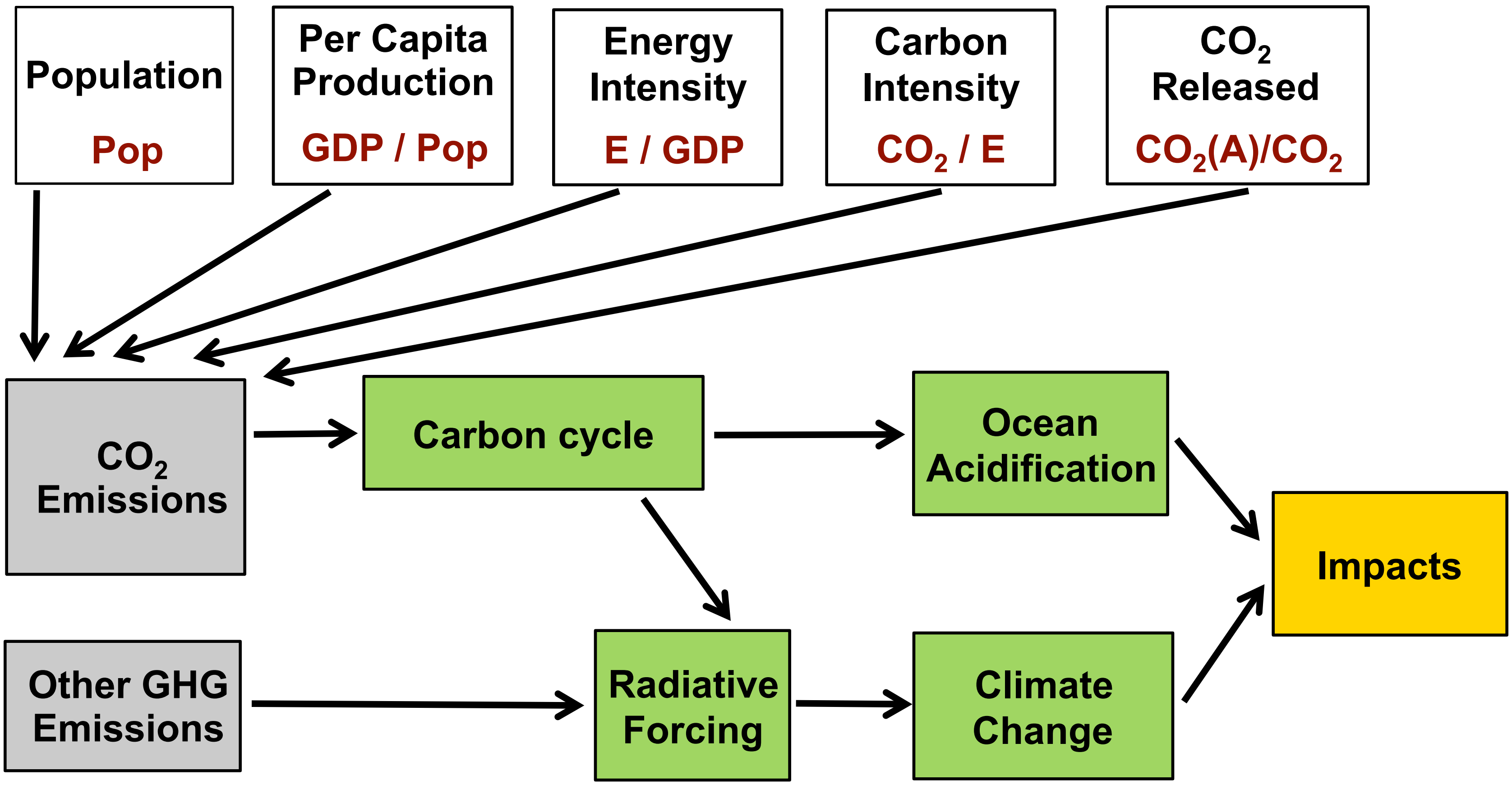
Source: Füssel (2007)

Carbon Dept and Wealth

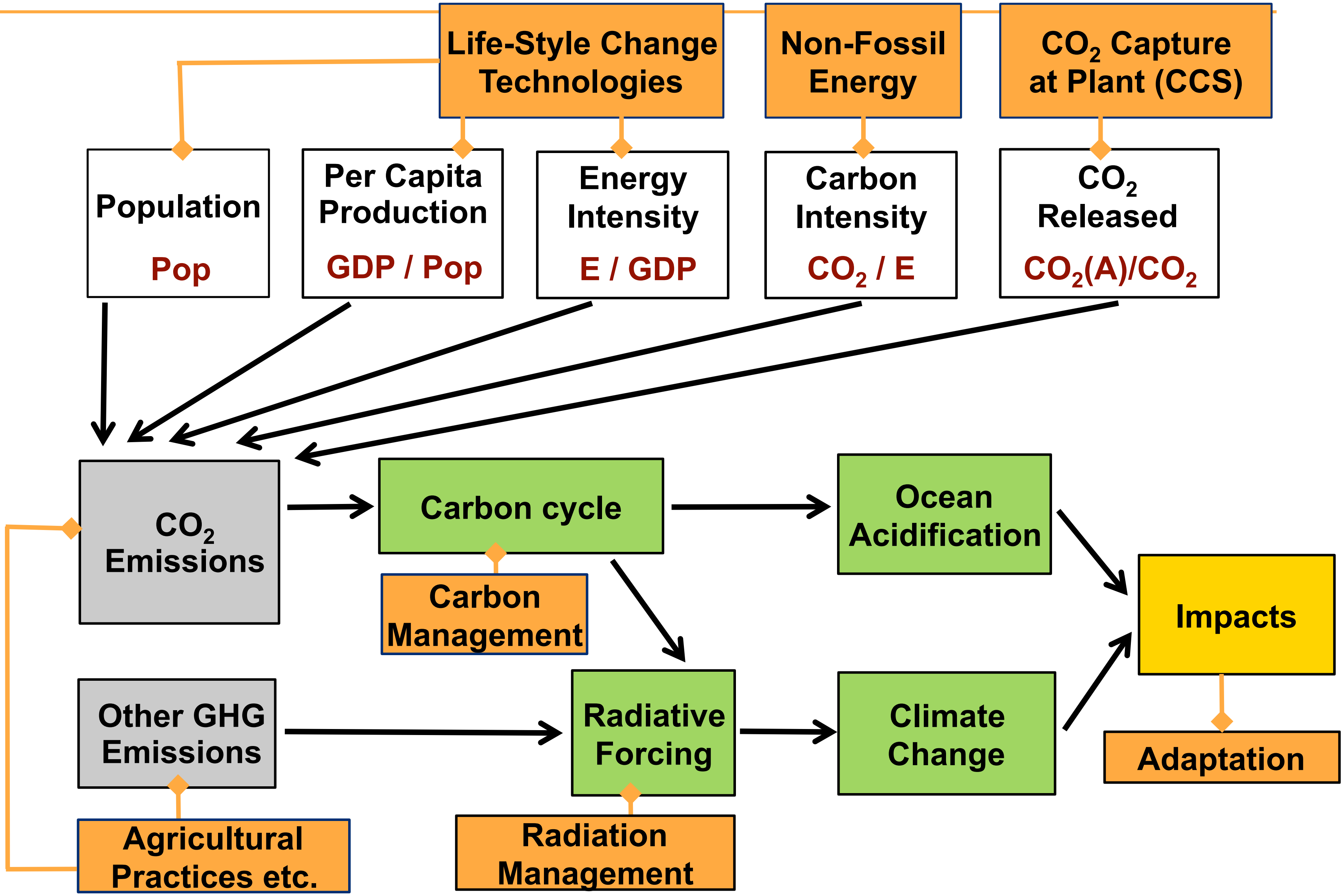


Source: Füssel (2007)

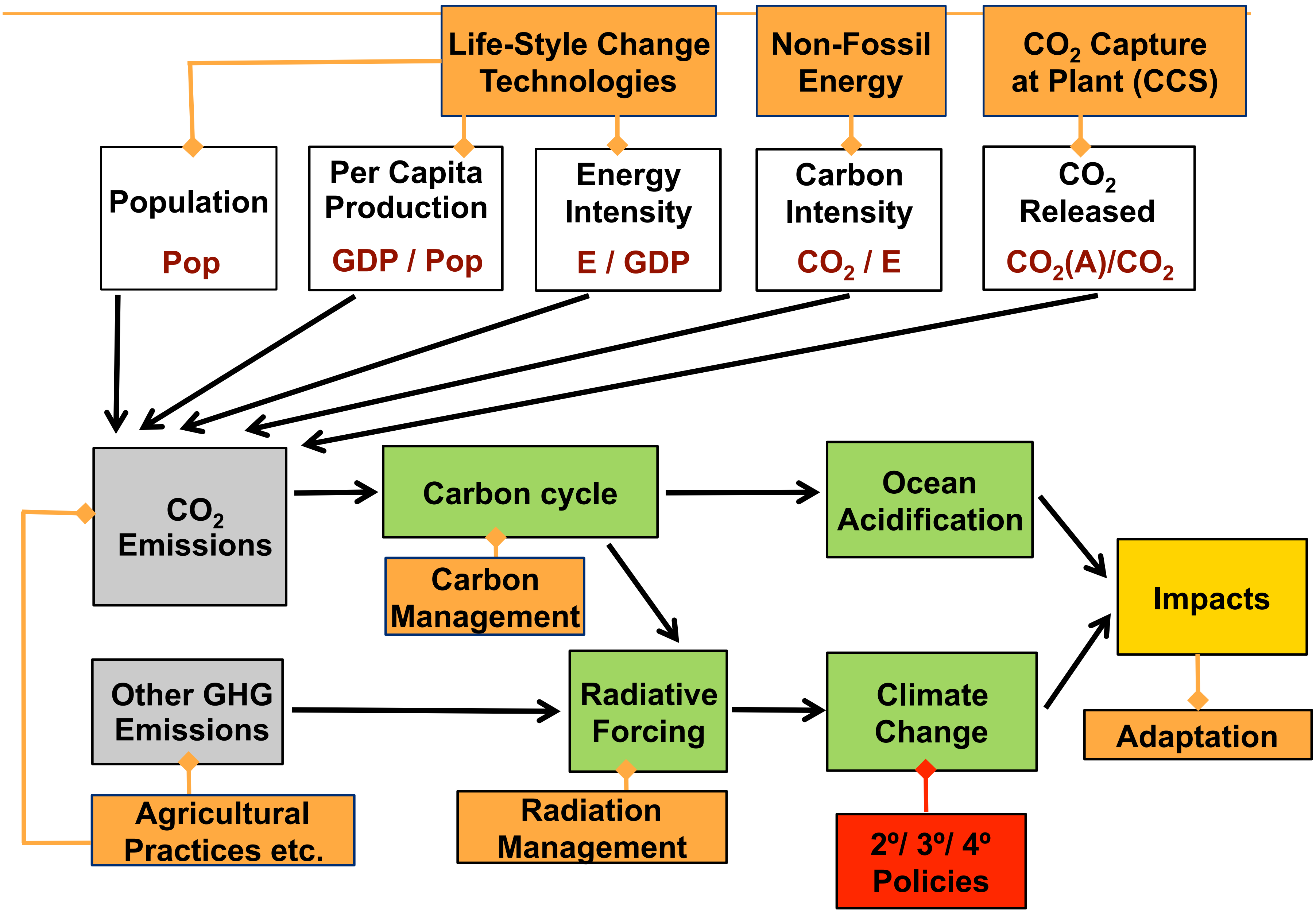
The Climate Problem



The Solution Space



Assessing the Solution Space



Measures to Decrease Carbon Intensity

Substituting coal and oil by natural gas

- Limited option! Coal, tar sands, and oil shale abundant

Substituting fossil fuels by

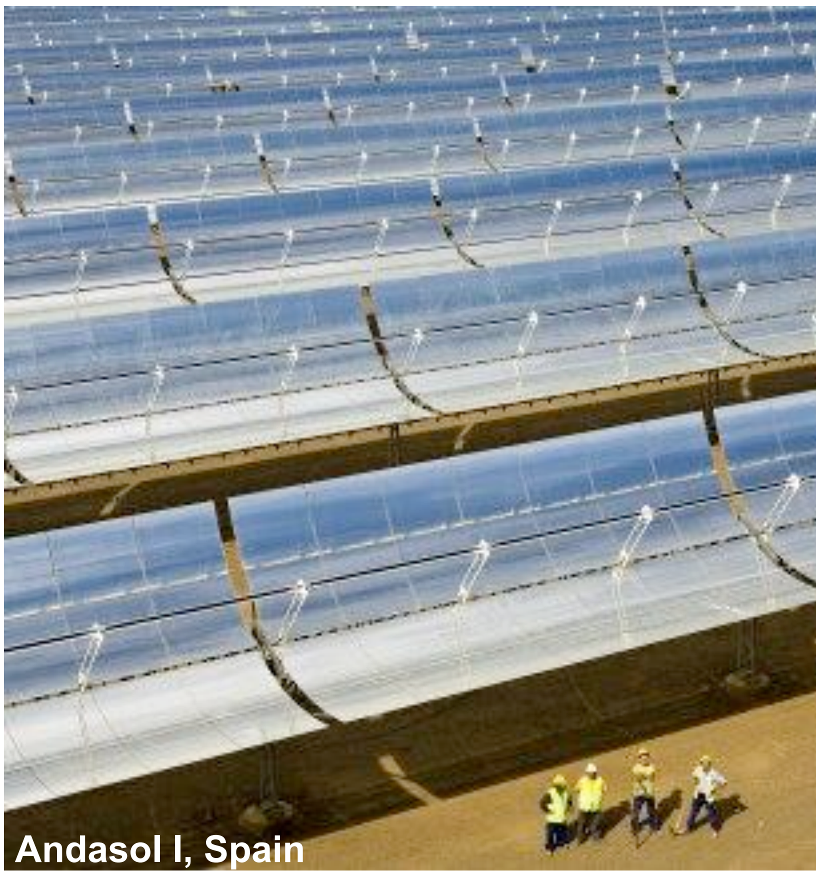
- Renewable energy (biomass, wind, solarthermal, PV)
- Nuclear energy (thermal reactors, fast breeders)
- Hydropower (limited potential)

Carbon Capture and Storage

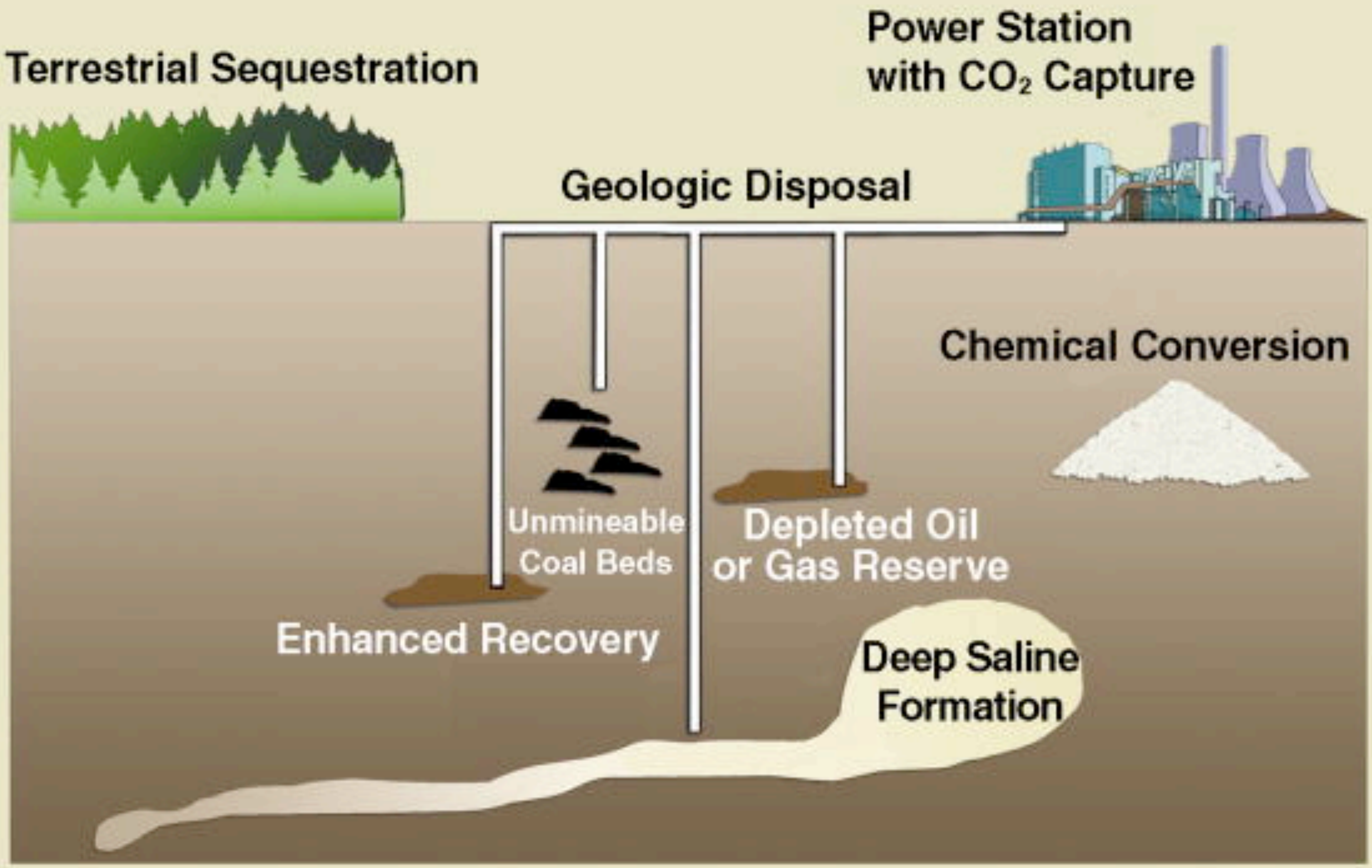
New Storage Technology Increases Reliability and Integration

New storage technologies open new potentials to integration.

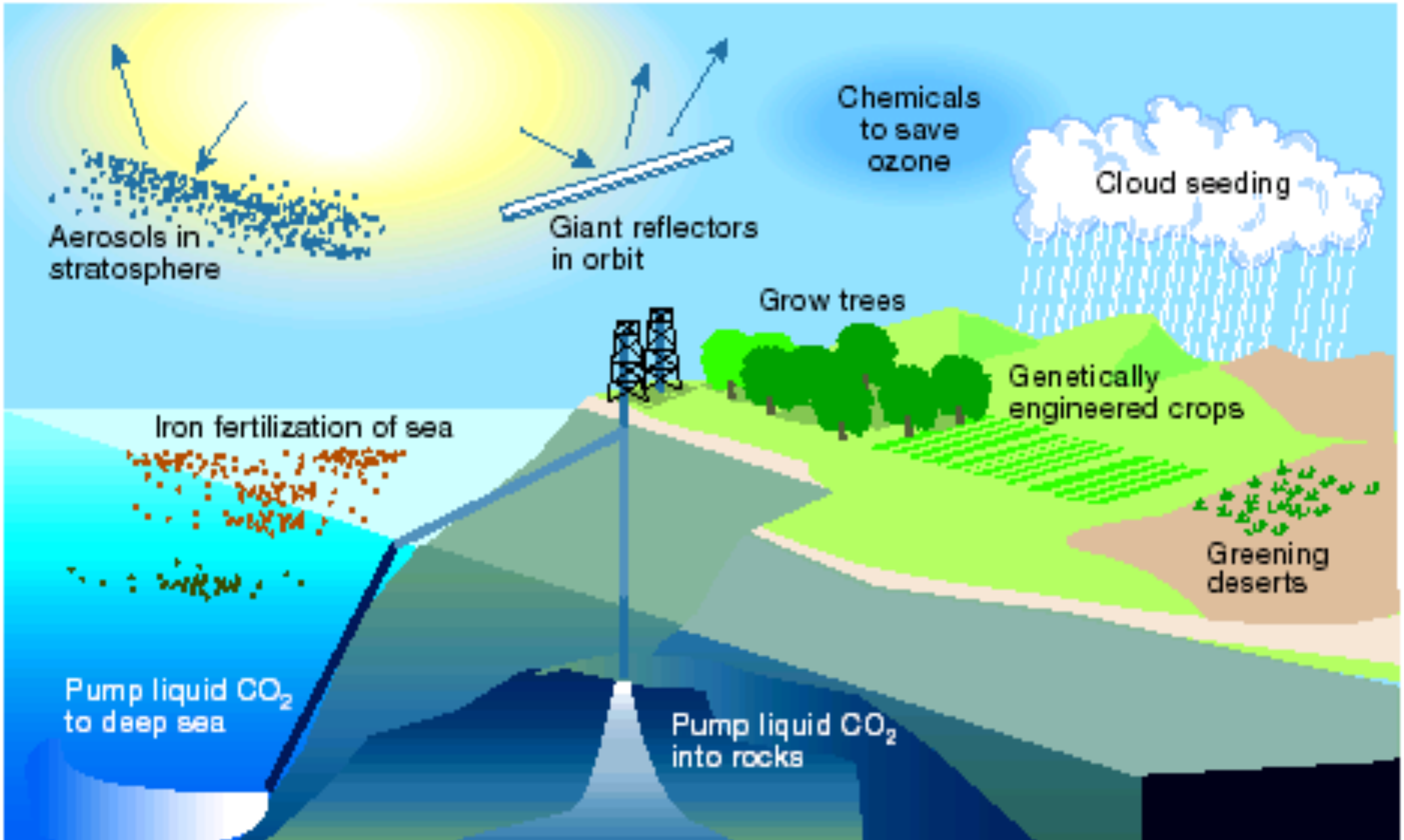
E.g. concentrating-solar-thermal-power-plant with molten salt thermal storage system with 7 hour capacity (bridging nights).



Carbon Sequestration Options



Geo-Engineering Options + Carbon Management



Schematic representation of various climate-engineering proposals (courtesy B. Matthews).

Assessment of Controlling the Radiation Balance

- Science is not clarified yet
- If geo-engineering can work, it will transform the climate debate substantially: The climate problem can then be solved unilaterally
- However, geo-engineering might then resemble the arms race problem

Are There Limits to Adaptation?

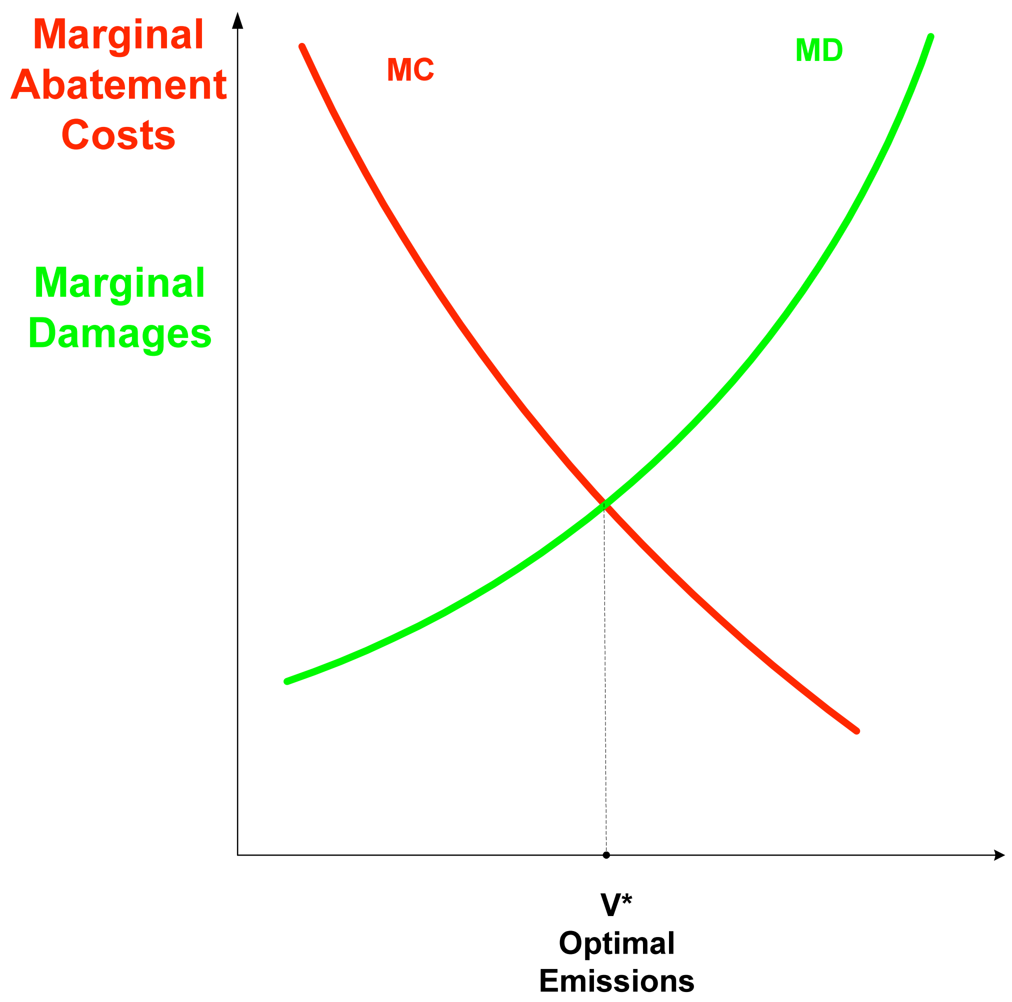
Dutch cow ready for sea-level rise?

How to Assess the Solution Space

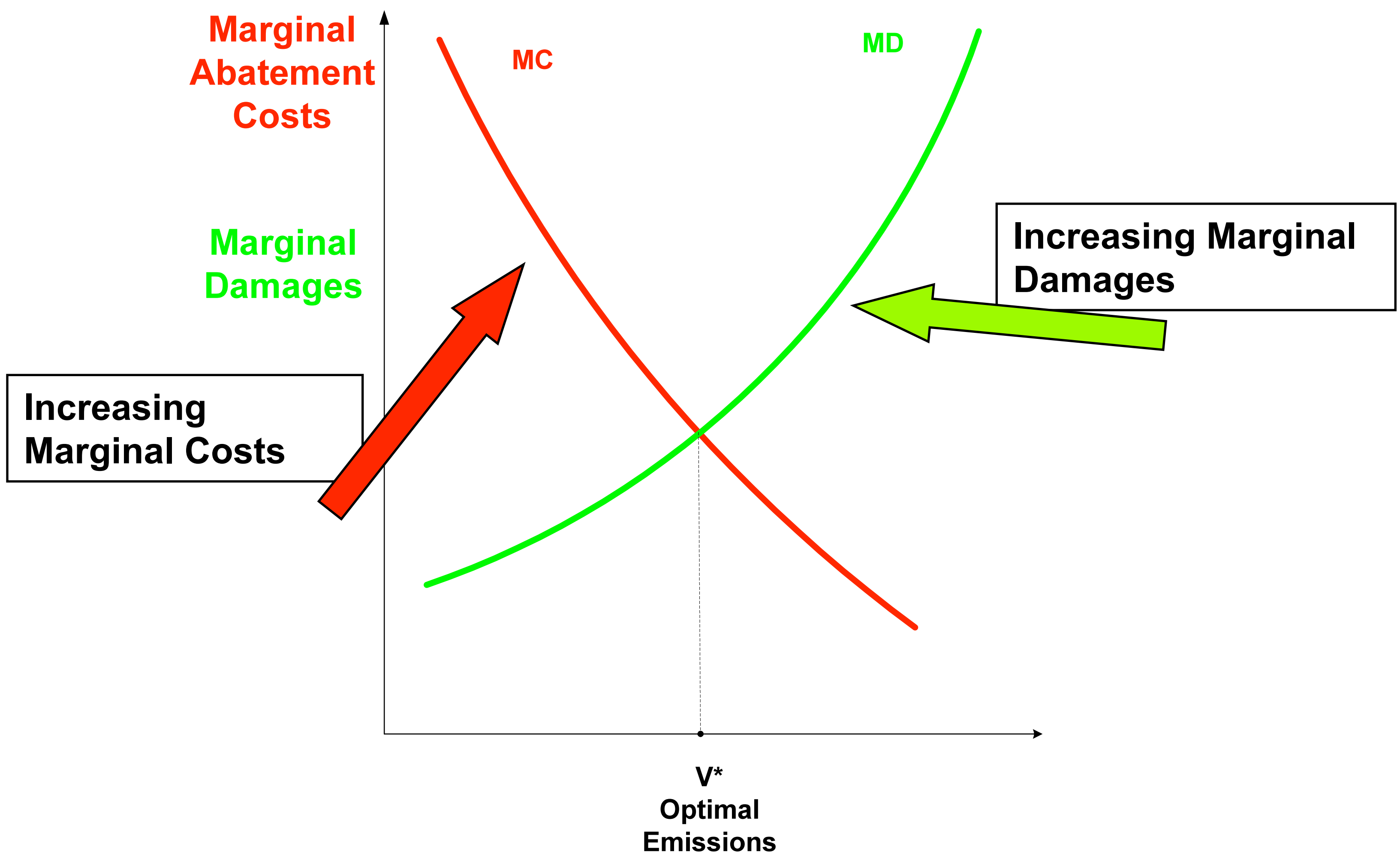
Identifying Acceptable Portfolios of Options:

- Cost-Benefit Analysis
- Cost-Effectiveness Analysis
- Multi-Criteria Analysis

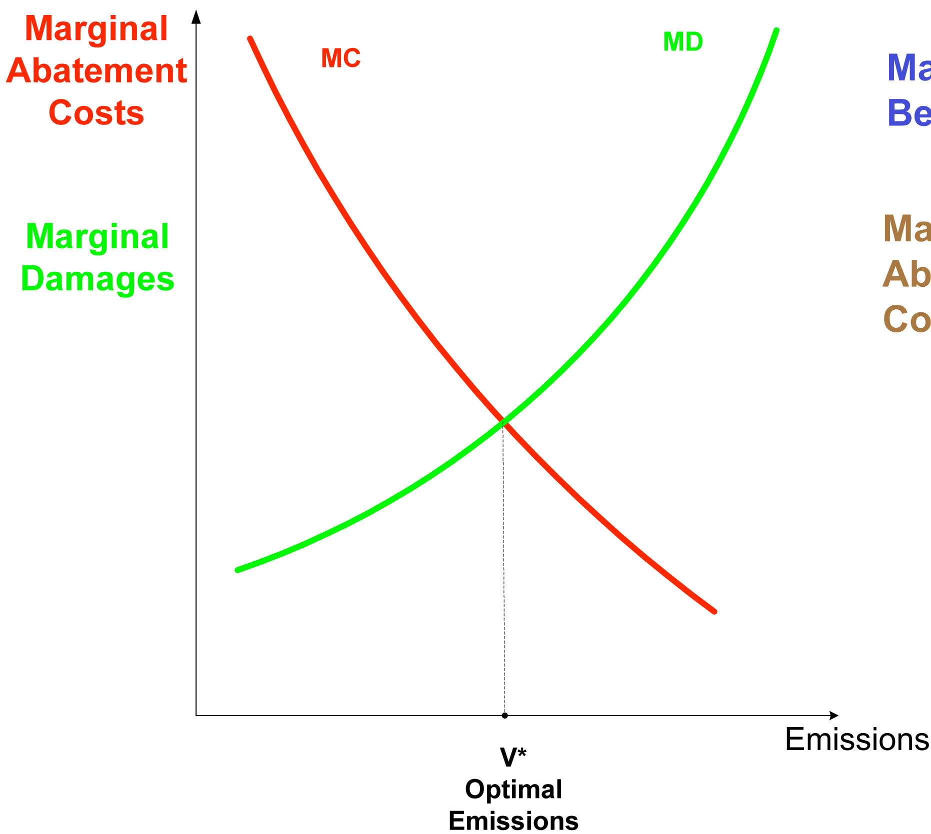
Cost-Benefit-Analysis

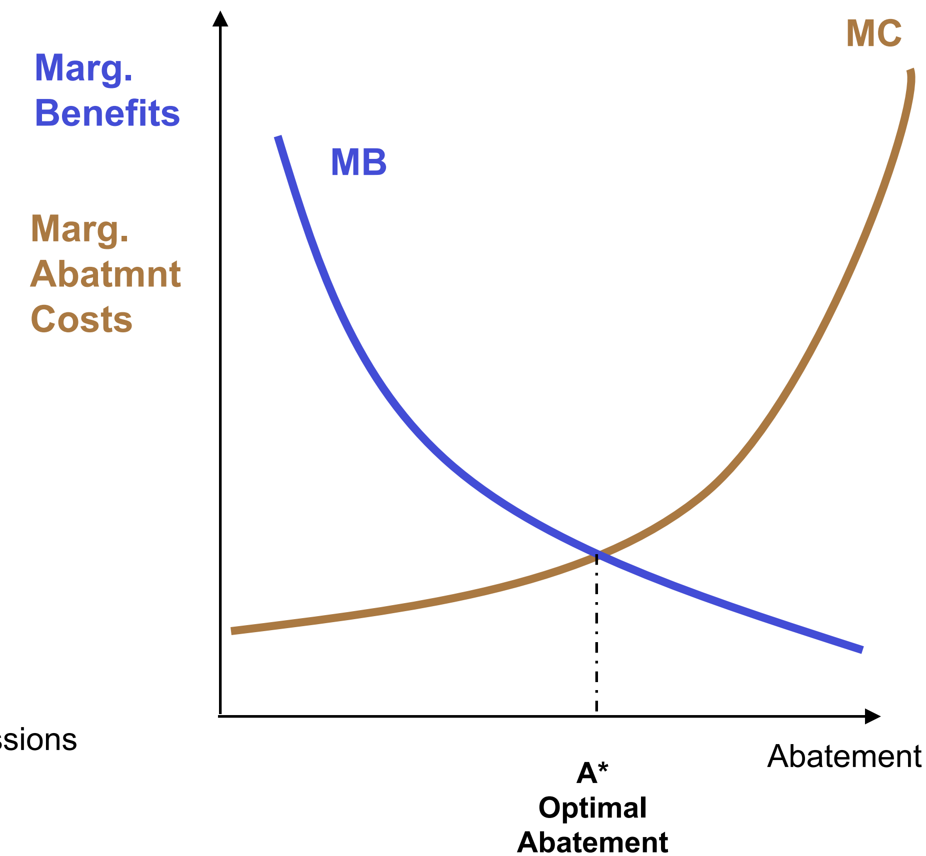


Cost-Benefit-Analysis



Efficient Pollution versus Efficient Abatement



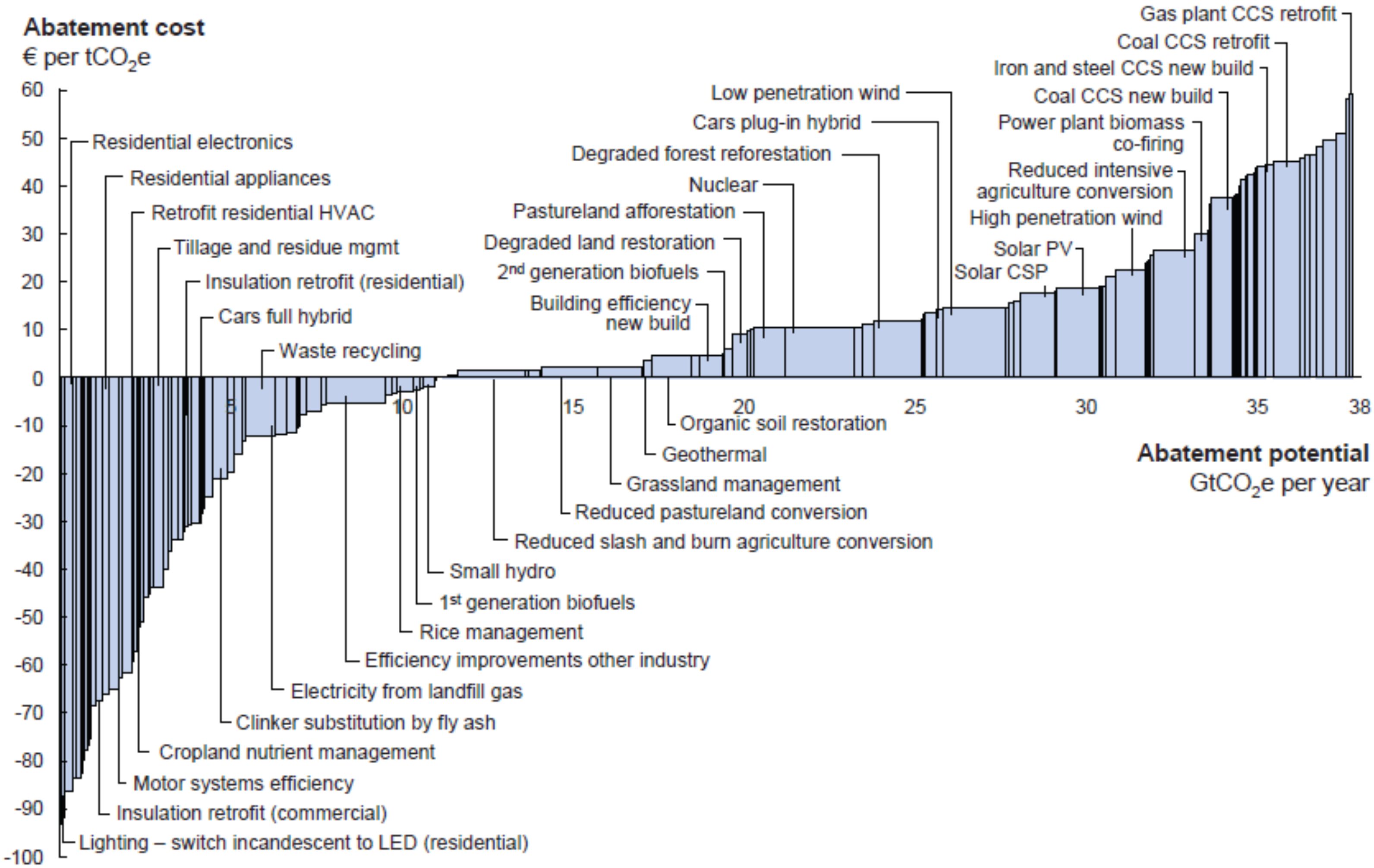


!

Benefits from Emissions = Costs of Abatement
Benefits from Abatement = Avoided Damages

Marginal Cost Curves

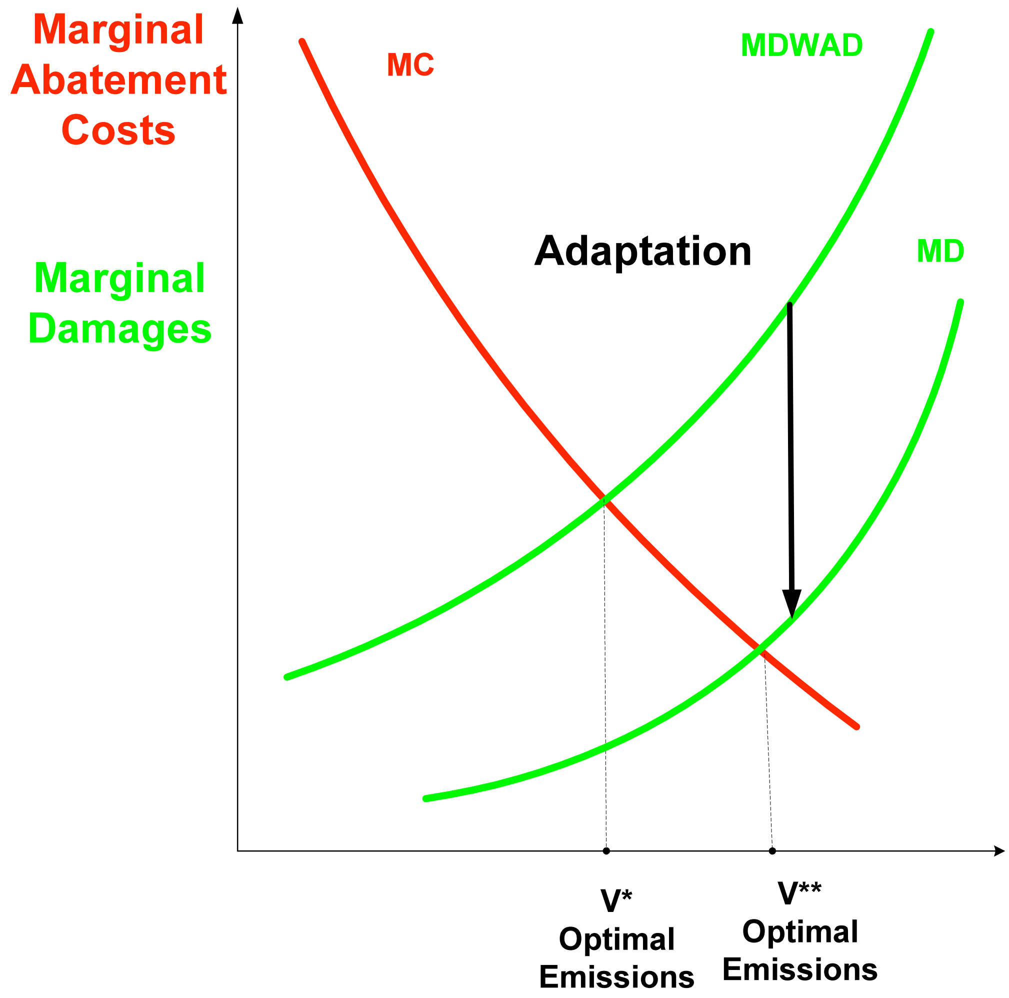
Global GHG abatement cost curve beyond business-as-usual – 2030



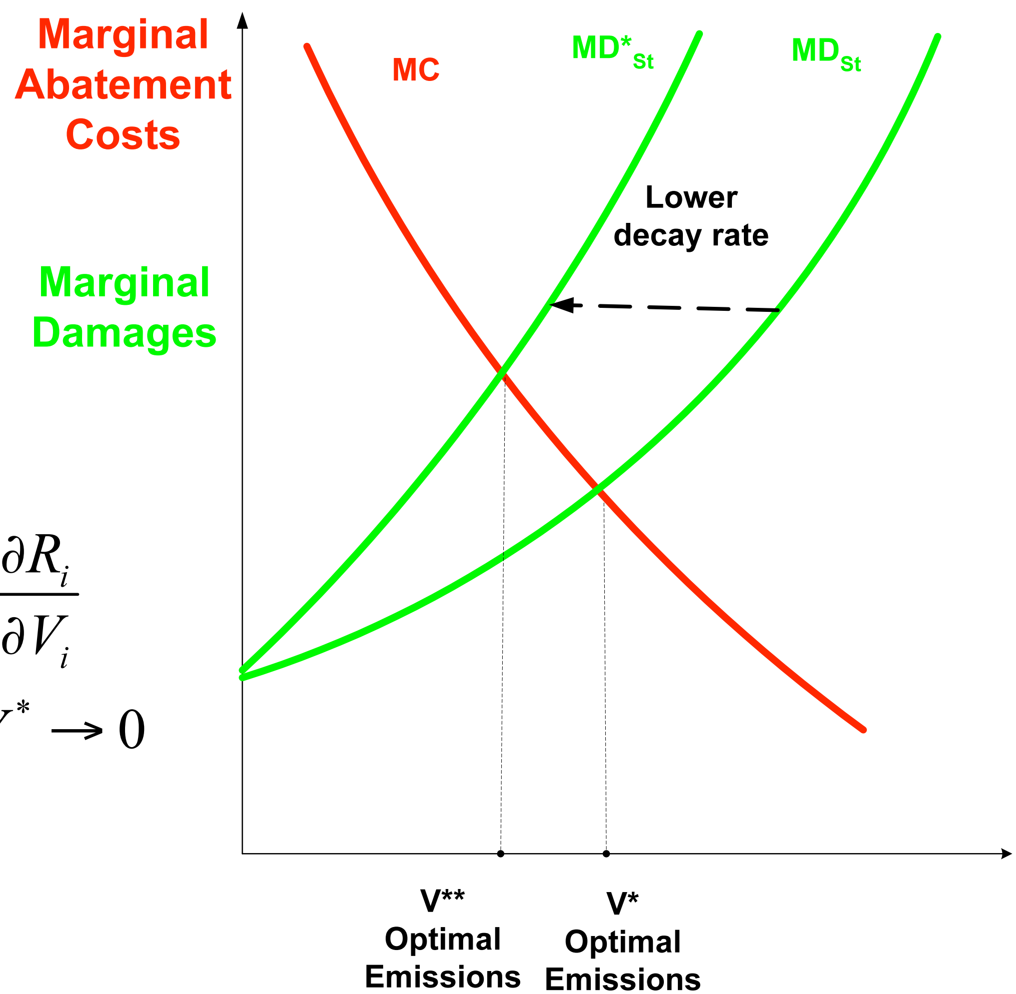
Note: The curve presents an estimate of the maximum potential of all technical GHG abatement measures below €60 per tCO_2e if each lever was pursued aggressively. It is not a forecast of what role different abatement measures and technologies will play.

Source: McKinsey (2009) Pathway to low carbon economy

Cost-Benefit-Analysis



Cost-Benefit-Analysis and Stock Pollutant

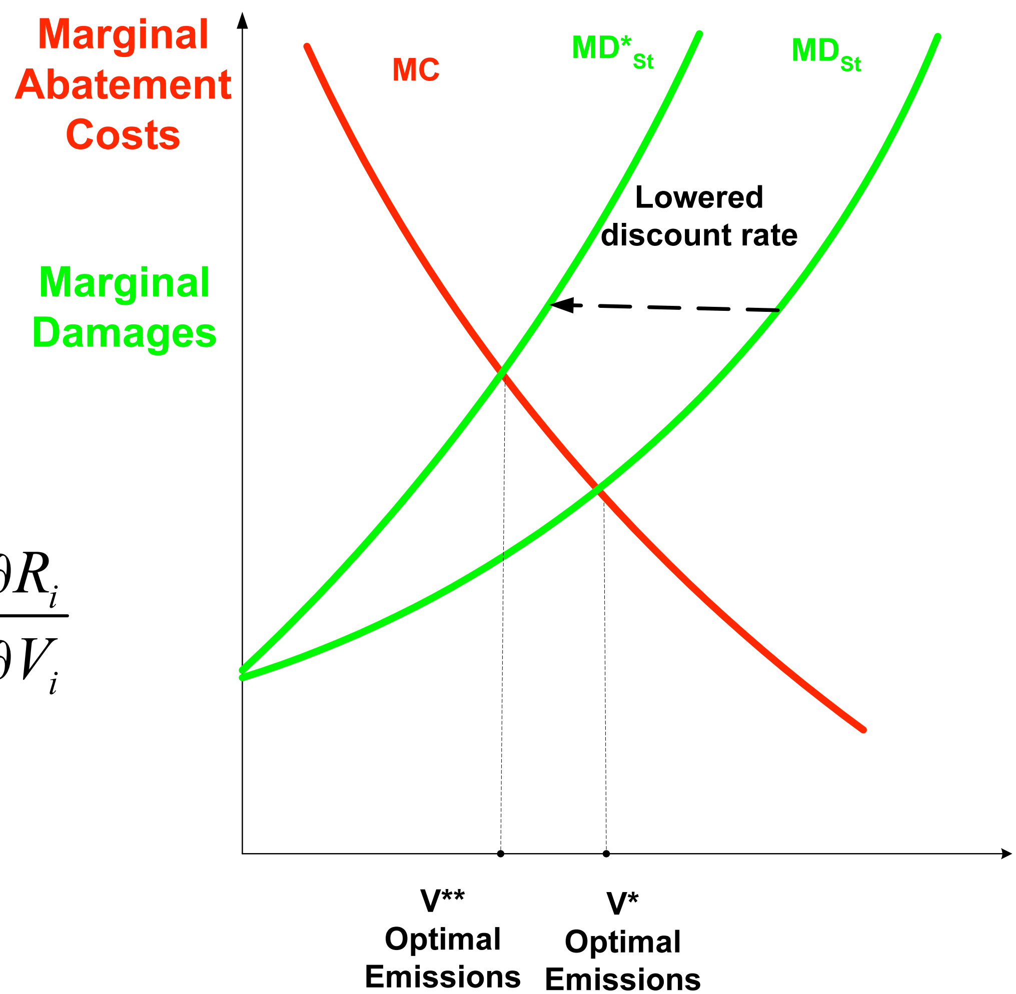


$$\frac{\partial D}{\partial V_i}\left(\frac{\alpha}{\alpha + r}\right) = \frac{\partial R_i}{\partial V_i}$$

For $\alpha \rightarrow 0,\ V^* \rightarrow 0$

Cost-Benefit-Analysis and Discounting

$$\frac{\partial D}{\partial V_i}\left(\frac{\alpha}{\alpha + r}\right) = \frac{\partial R_i}{\partial V_i}$$



What Can We Learn from This Simple Model

- The *discount rate* determines climate policy. However, the debate on discounting is driven by *ethical judgements*. This might be the reason why many economists are puzzled by this issue

- The assessment of *mitigation, damage and adaptation* costs determines also the climate policy ramp. This assessment is driven by *scientific insights*.

The Debate on Discounting

- A low discount rate leads to more ambitious climate policy.

- However, it is not easy to justify a low discount rate.
  - Inter- and intragenerational justice has to be taken into account
  - Uncertainty

Stern's Welfare Function

$$W = \int_0^\infty \frac{C^{1-\eta}}{1-\eta} e^{-\delta t} dt$$

W = Welfare

C = Consumption

η = Intragenerational Equity

δ = Pure Rate of Time Preference

Stern‘s Welfare Function

$$W = \int_0^\infty \frac{C^{1-\eta}}{1-\eta} e^{-\delta t} dt$$

W= Welfare

C= Consumption

η = Intragenerational Equity

δ = Pure Rate of Time Preference (Intergenerational Fairness)

Stern's Welfare Function

$$W = \int_0^\infty \frac{C^{1-\eta}}{1-\eta} e^{-\delta t} dt$$

W = Welfare

C = Consumption

η = Intragenerational Equity

δ = Pure Time Preference Rate

$$\eta = -\frac{\frac{\Delta U'}{U'}}{\frac{\Delta C}{C}}$$

The Problem of Ethical Duality

Both parameters determine the overall investment rate *i* in a simple Ramsey model:

$$r = \delta + a\eta$$

$$s = \frac{a+n}{\delta + a\eta}\beta$$

a = Labour Productivity

β = Capital Income Share

n = Population Growth

Investment Rate and Ethical Duality

Intergenerational inequity

Inequity between rich and poor

η \ δ	0.1 %	1 %	5 %
2	18 %	16 %	12 %
1	36 %	30 %	18 %
0.5	70 %	51 %	24 %

$a = 5\ \%,\ n = 1\ \%,\ \beta = 30\ \%$

Investment Rate and Ethical Duality

Intergenerational inequity

Inequity between rich and poor

η \ δ	0.1 %	1 %	5 %
2	18 %	16 %	12 %
1	36 %	30 %	18 %
0.5	70 %	51 %	24 %

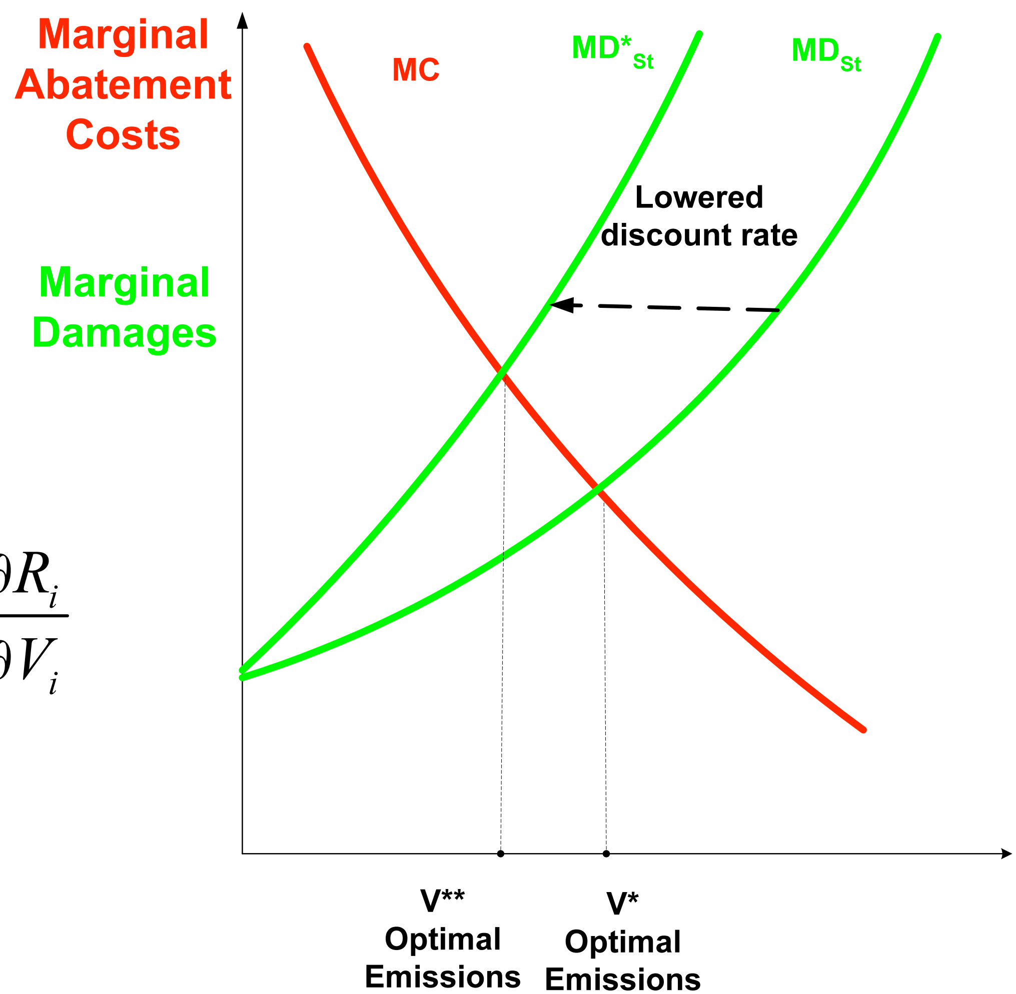
Equity

a = 5 %, n = 1 %, β = 30 %

Inequity

Cost-Benefit-Analysis and Discounting

$$\frac{\partial D}{\partial V_i}\left(\frac{\alpha}{\alpha + r}\right) = \frac{\partial R_i}{\partial V_i}$$



Arguments for Low Time Preference

- Some economists argue that the assumption of *intergenerational equality* is ethically binding. This leads to an exactly zero pure rate of time preference δ

- But even taking intergenerational equality as given, the exogenous risk of *civilizational extinction* might legitimate a small nonzero δ

- However, as shown a low time preference rate does not justify a low discount rate. This implies that an option for more inter- and intragenerational justice does not lead to an ambitious climage policy.

Uncertainty

Subjective uncertainty about the growth rate *g* of consumption leads to smaller expected discount rates that can then be represented by *risk aversion*.

Capital Asset Price Models (CAP)

The choice between the risk-free discount rate r^f and the risky rate r^E depends on the correlation β between mitigation investments and the growth rate of consumption *g.*

Risk-free discount rate

$$r^f = \delta + \eta\mu - \frac{1}{2}\eta^2 s^2$$

growth rate *g* = N(μ,s²)

Risky Discount Rate

$$r^E = \ln E[R^E]$$

Economy-wide Risks

r^E is the gross arithmetic return on equity

The relevant discount rate for climate policy

$$r = -[\ln(\beta \exp(-100 r^E) + (1-\beta)\exp(-100 r^f)]/100$$

benefits 100 years from now

Lessons Learned from CAP

Using historical data

β=0 => $r = r^f = 1\%$ β=1/2 => $r = 1.7\%$ β=1 => $r = r^E = 7\%$

- Interestingly, the discount rate for medium values of β is much smaller than what could be expected from a linear relationship

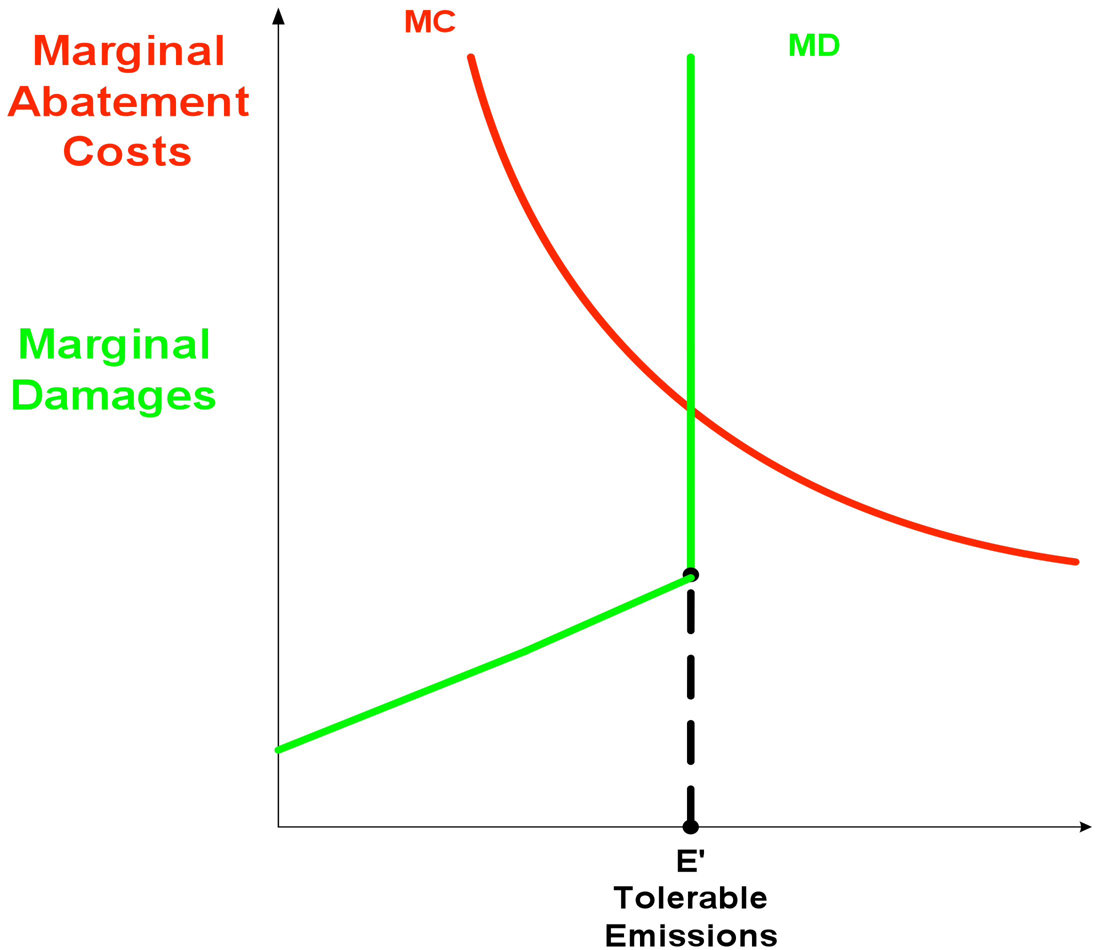
- This could be used to argue for smaller discount rates and thus for more stringent mitigation action

- Finally, the CAP tells us that the choice of the appropriate discount rate is an empirical issue

The Implication of Ethical Duality

- If both ethical parameters are chosen in a proper way, ethics basically has no impact on climate policy.
- The information required to determine η in all its roles is not available
- Ethics is not of much help to resolve the discounting issue
- It is much more important to understand the nature of *damage* and *mitigation* costs.

What about Tippint Points?

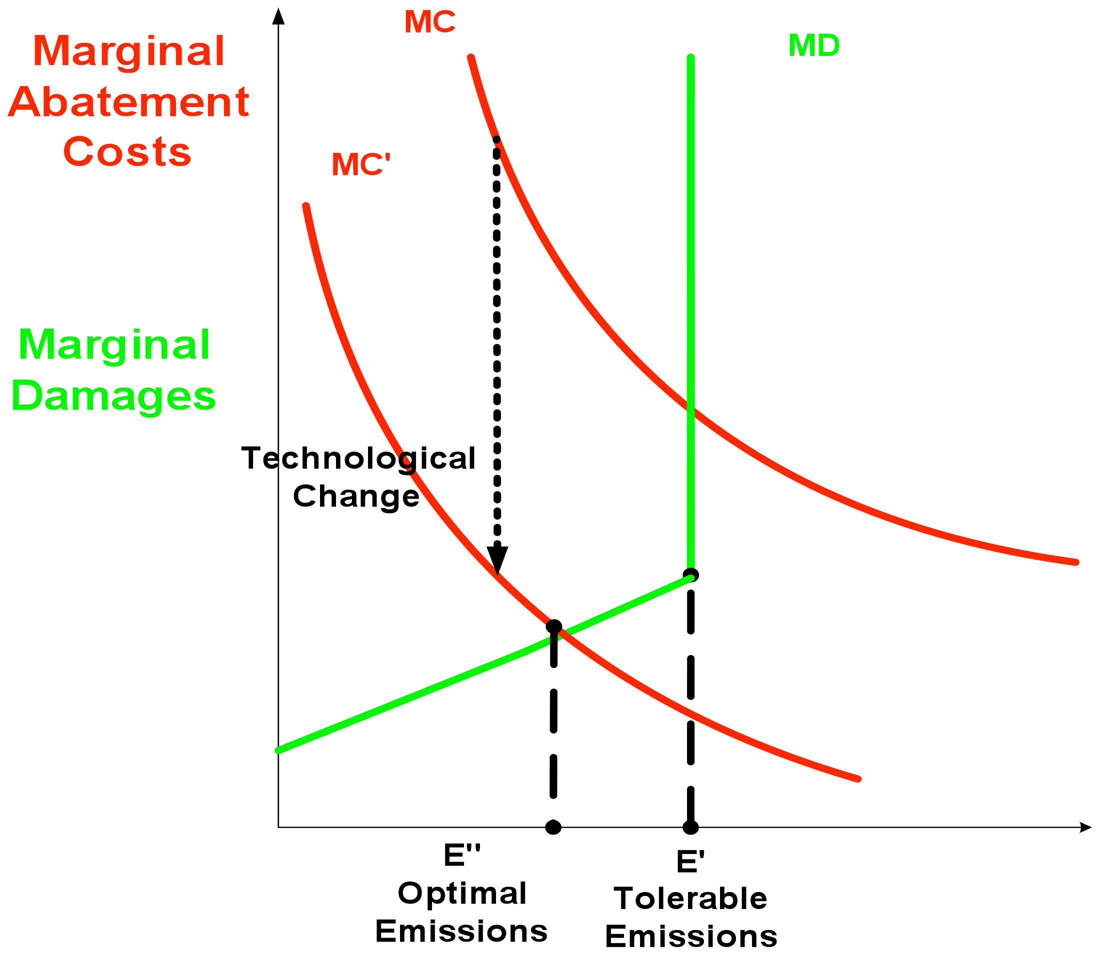


Why a Target Approach Might be Justified

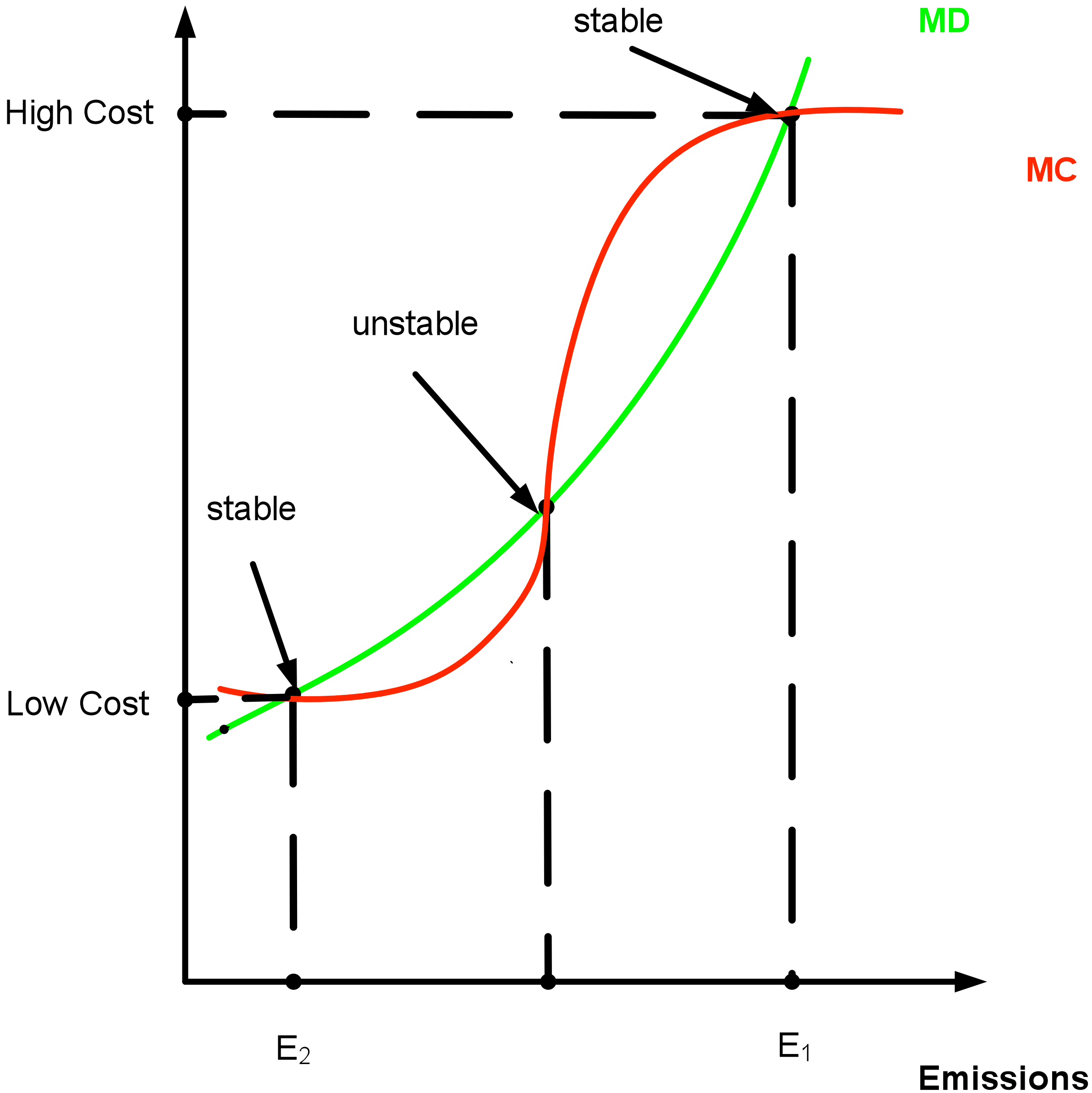
- Climate Change might activate tipping points

- The basis for calculating the social costs of carbon is weak

What about Technological Change?

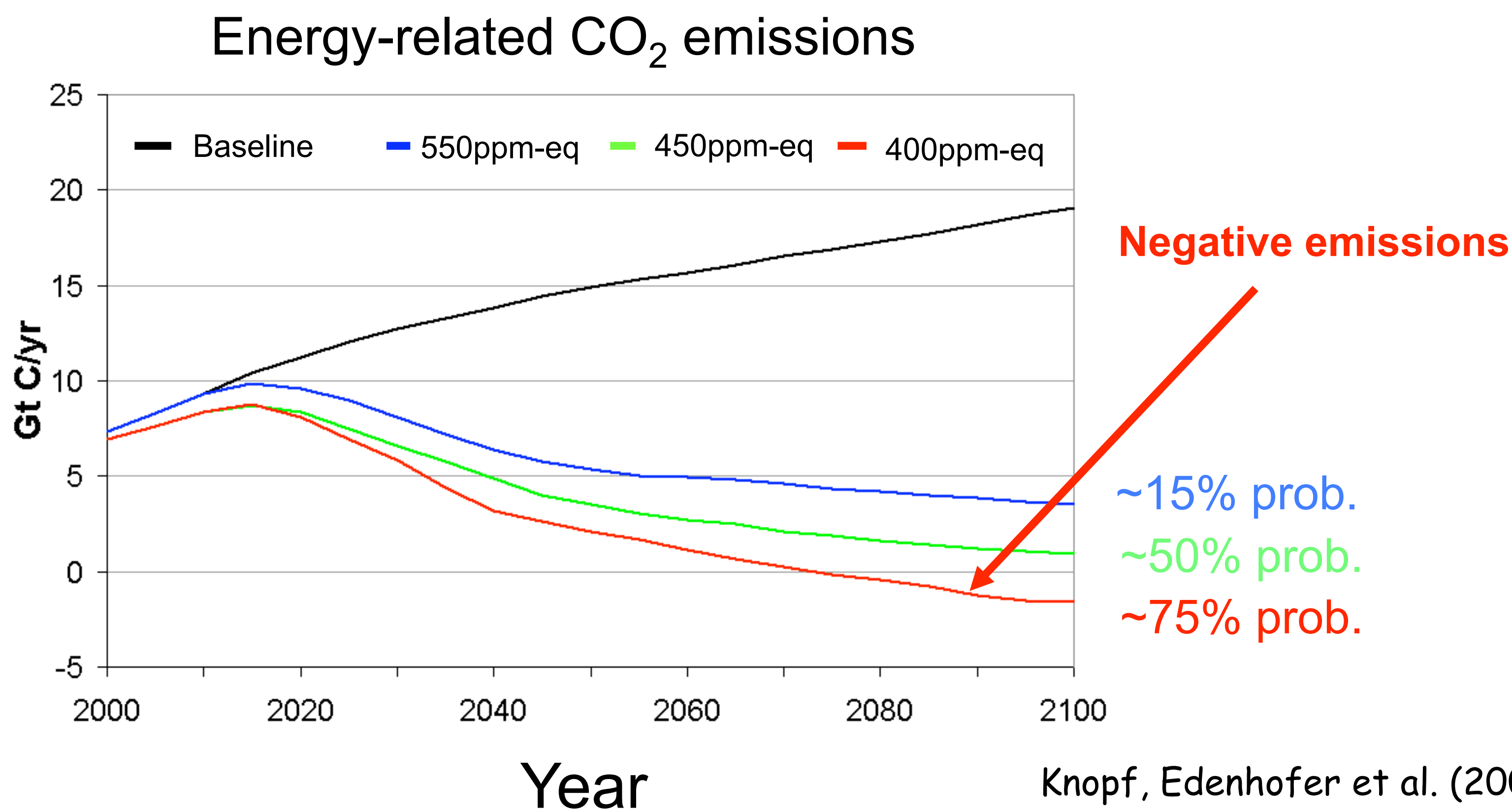


Multiple Equilibria and Non-Convex Optimization



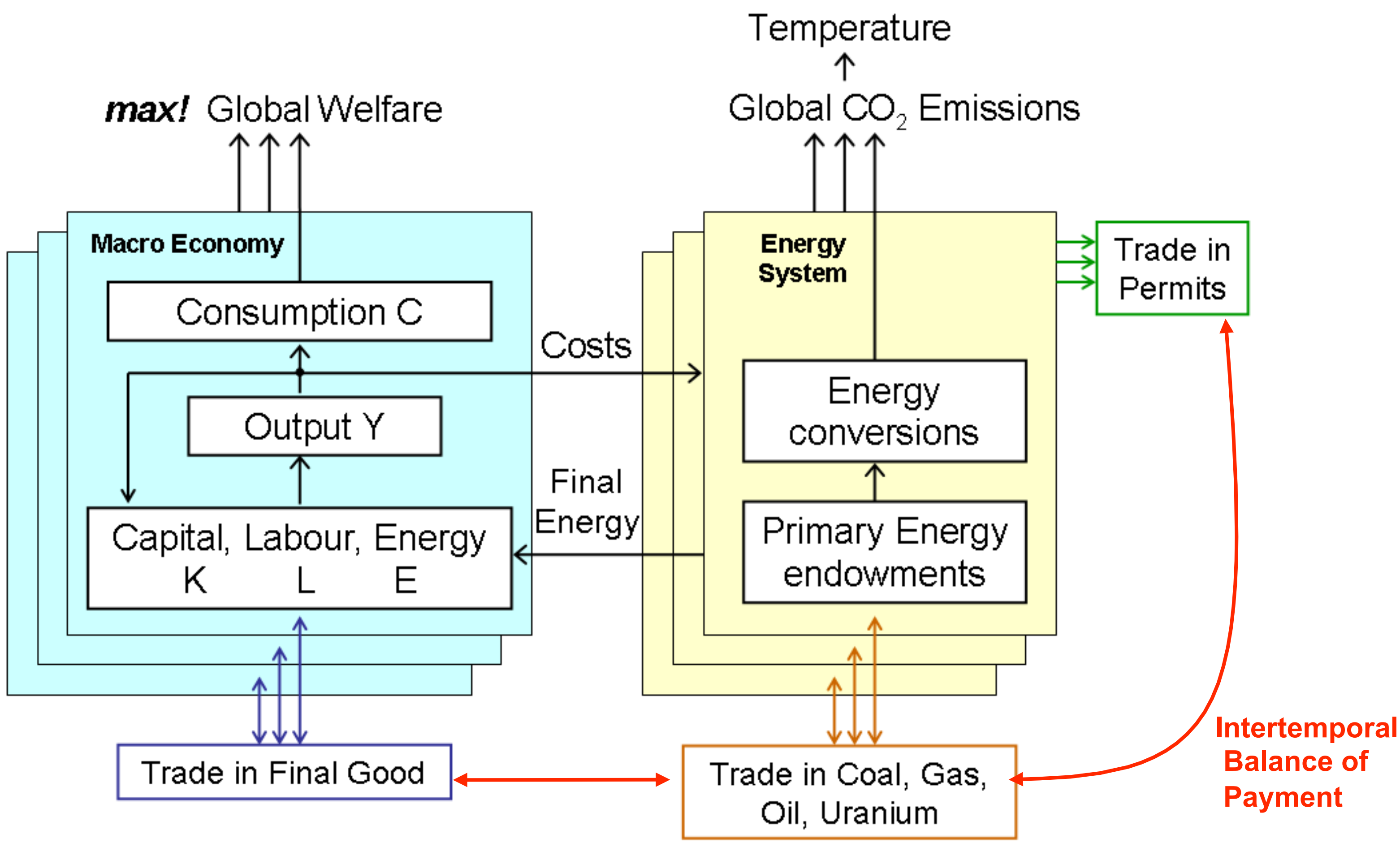
The Economics of Atmospheric Stabilization

3 stabilisation targets with different probabilities to reach the 2° target:
550ppm-eq, 450ppm-eq, 400ppm-eq

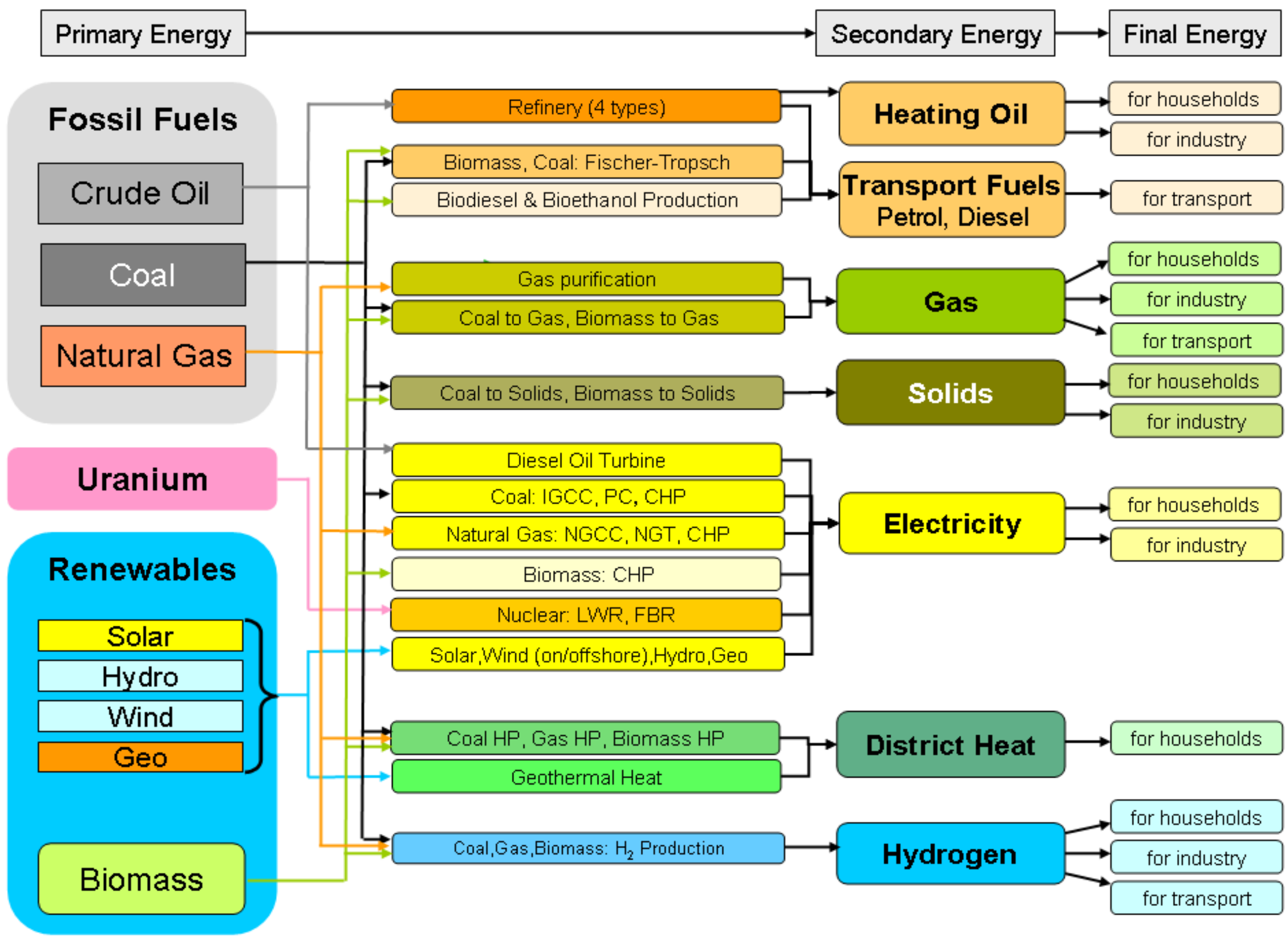


Knopf, Edenhofer et al. (2009)

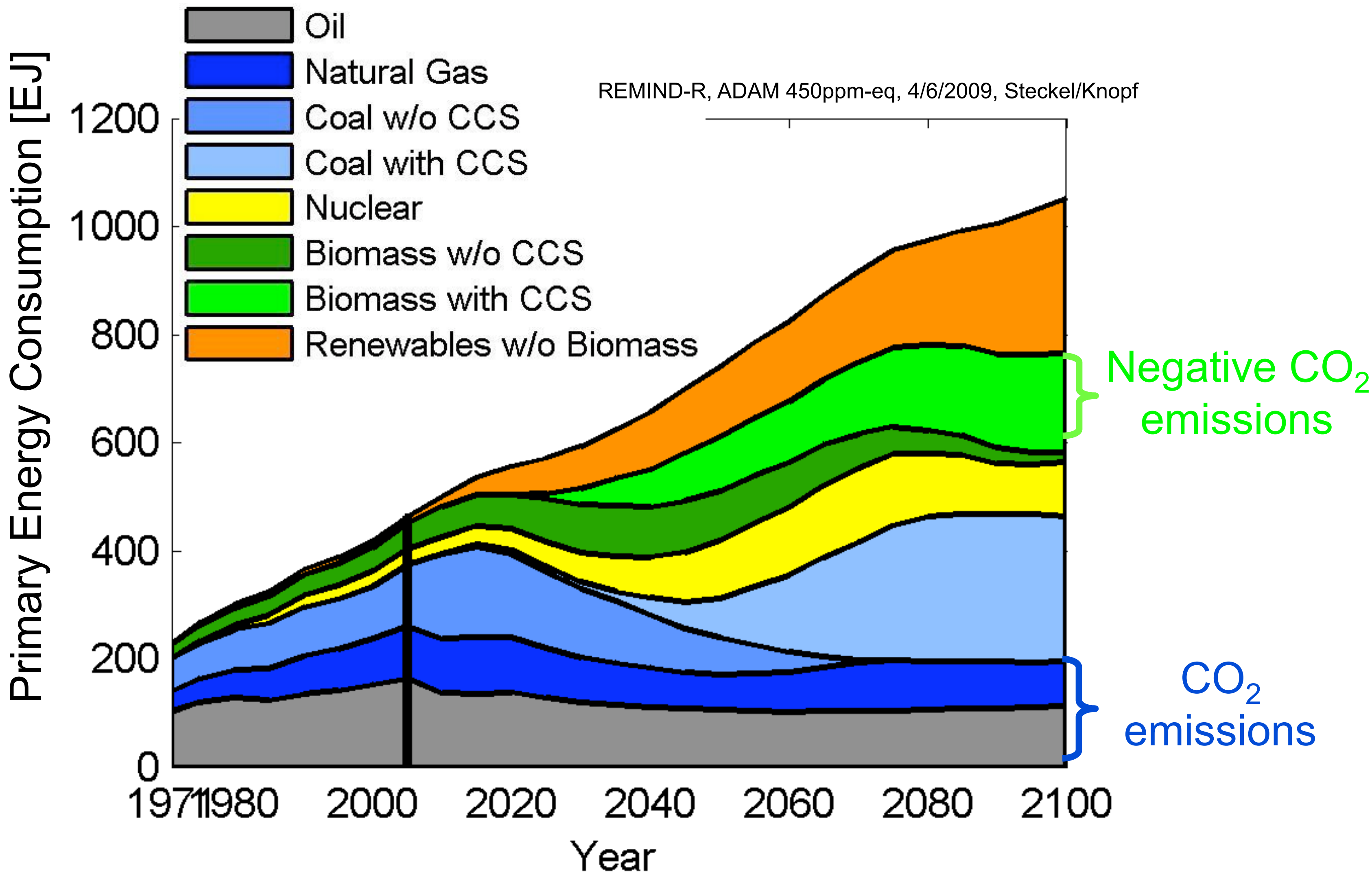
The Model REMIND



The Energy System in REMIND

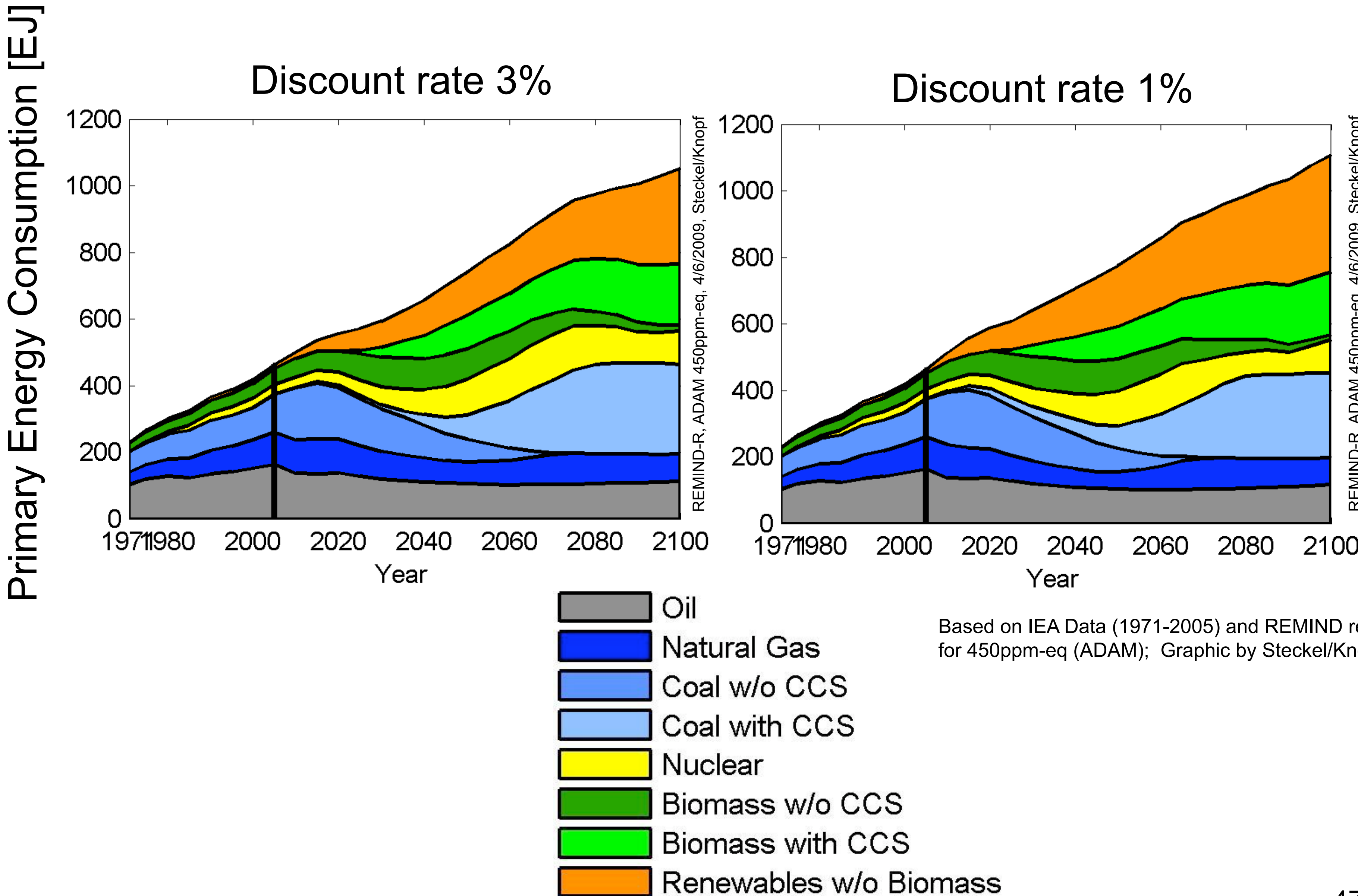


The Great Transformation



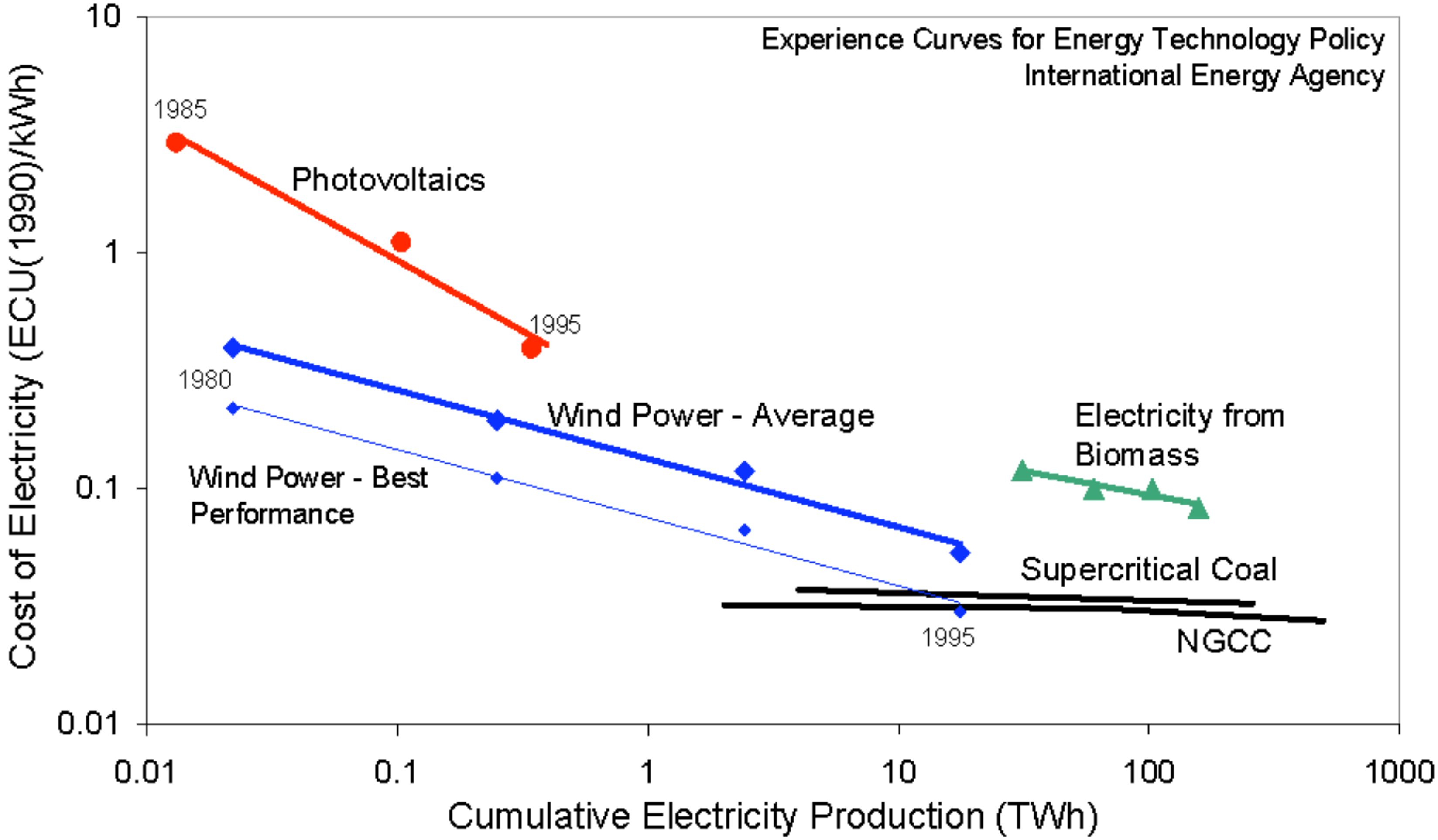
Based on IEA Data (1971-2005) and REMIND-R results for 450ppm-eq (ADAM); Graphic by Steckel/Knopf (PIK)

Discounting and Technological Change



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

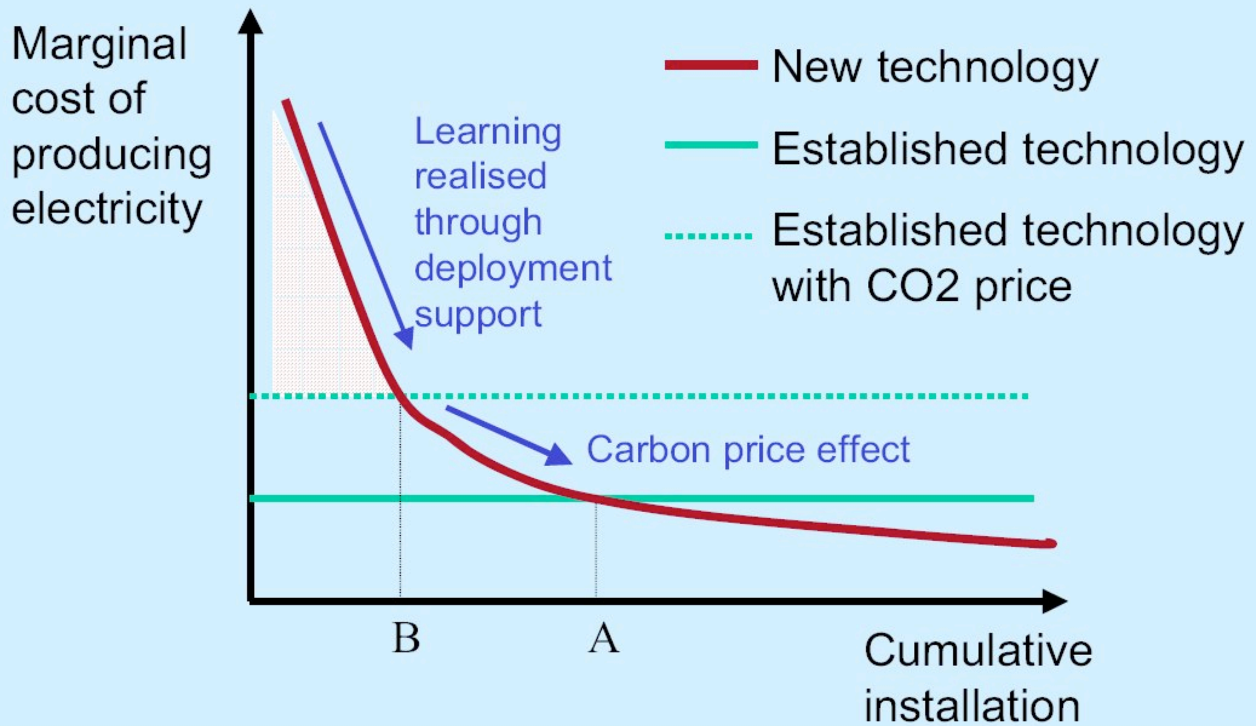
Electric Technologies in EU 1980-1995



Source: IEA (2000): Experience Curves for Energy Technology Policy; p. 21

Learning Curves and the Portfolio of Mitigation Options

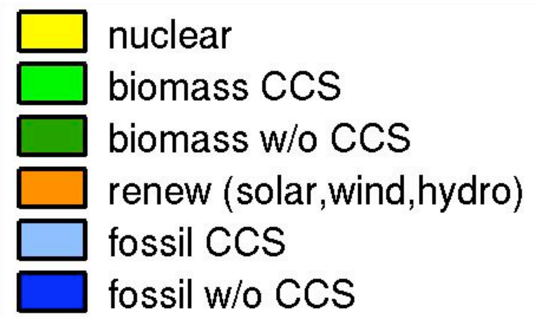
Figure 16.6 Interaction between carbon pricing and deployment support[32]

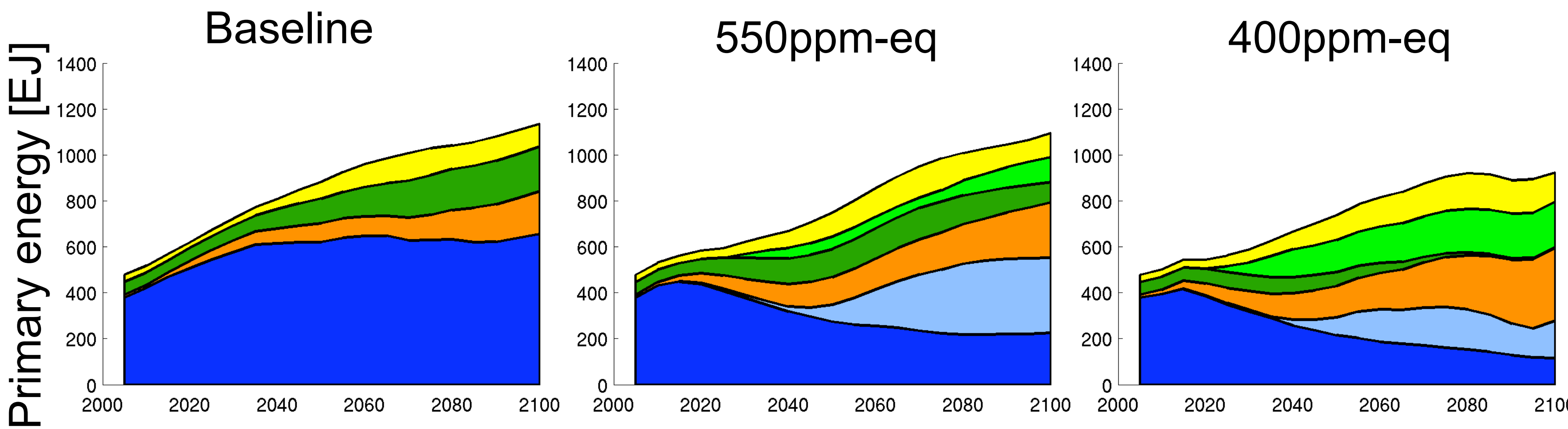


Source: Stern Review 2006

Energy Mix of a Decarbonized Future

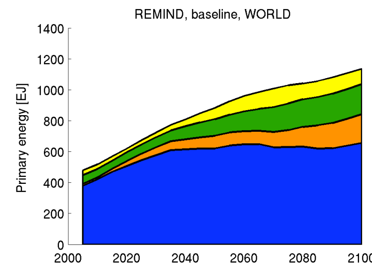
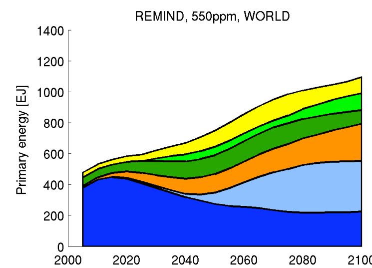
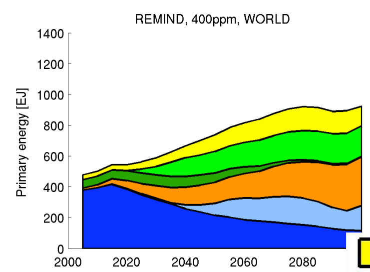
Example: REMIND-R

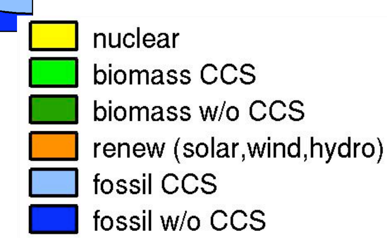




Knopf, Edenhofer et al. (2009)

There is more than one path towards a carbon-free economy

	MERGE	TIMER	POLES	REMIND	E3MG
baseline					
550 ppm					
400 ppm					



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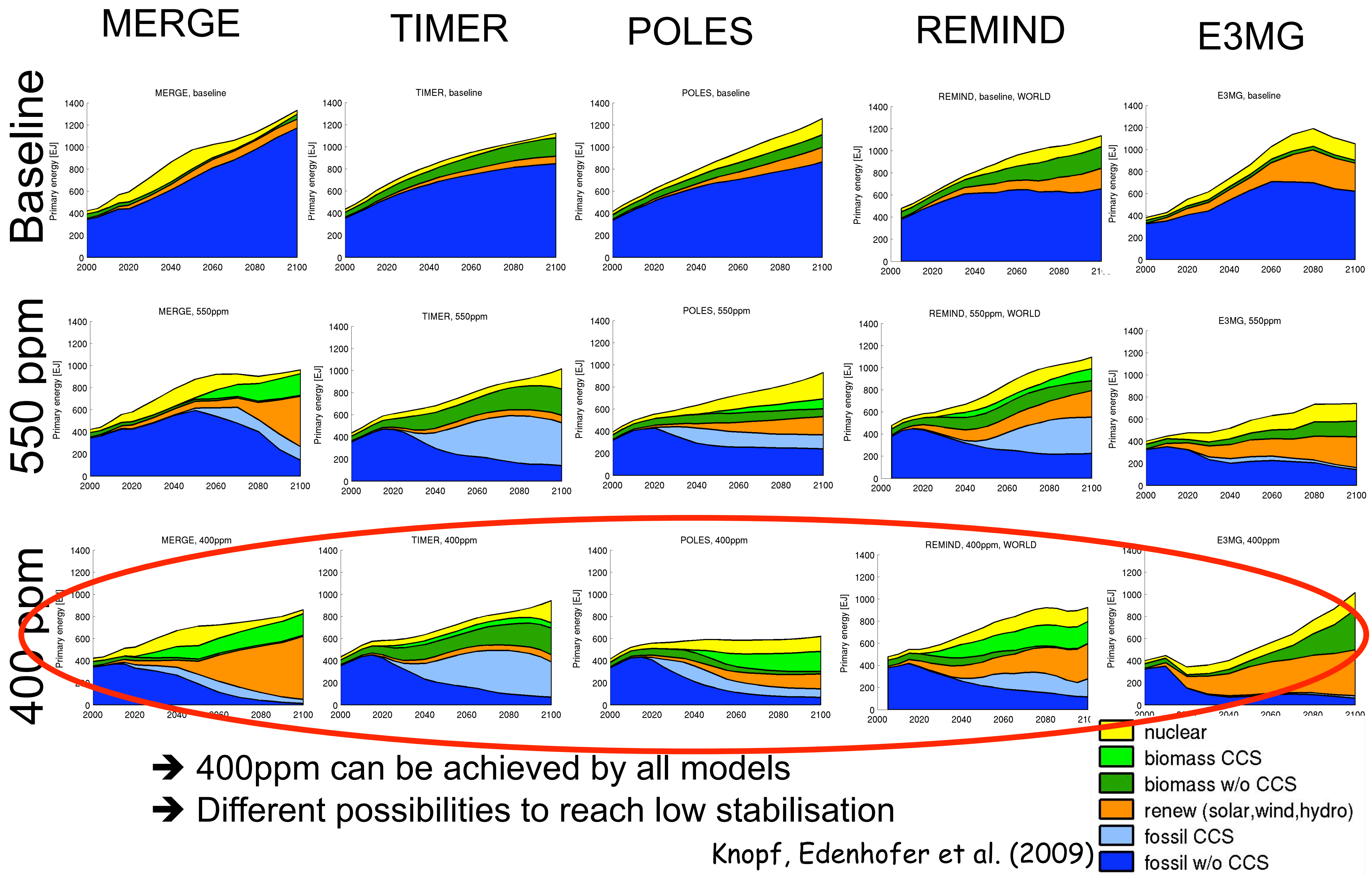
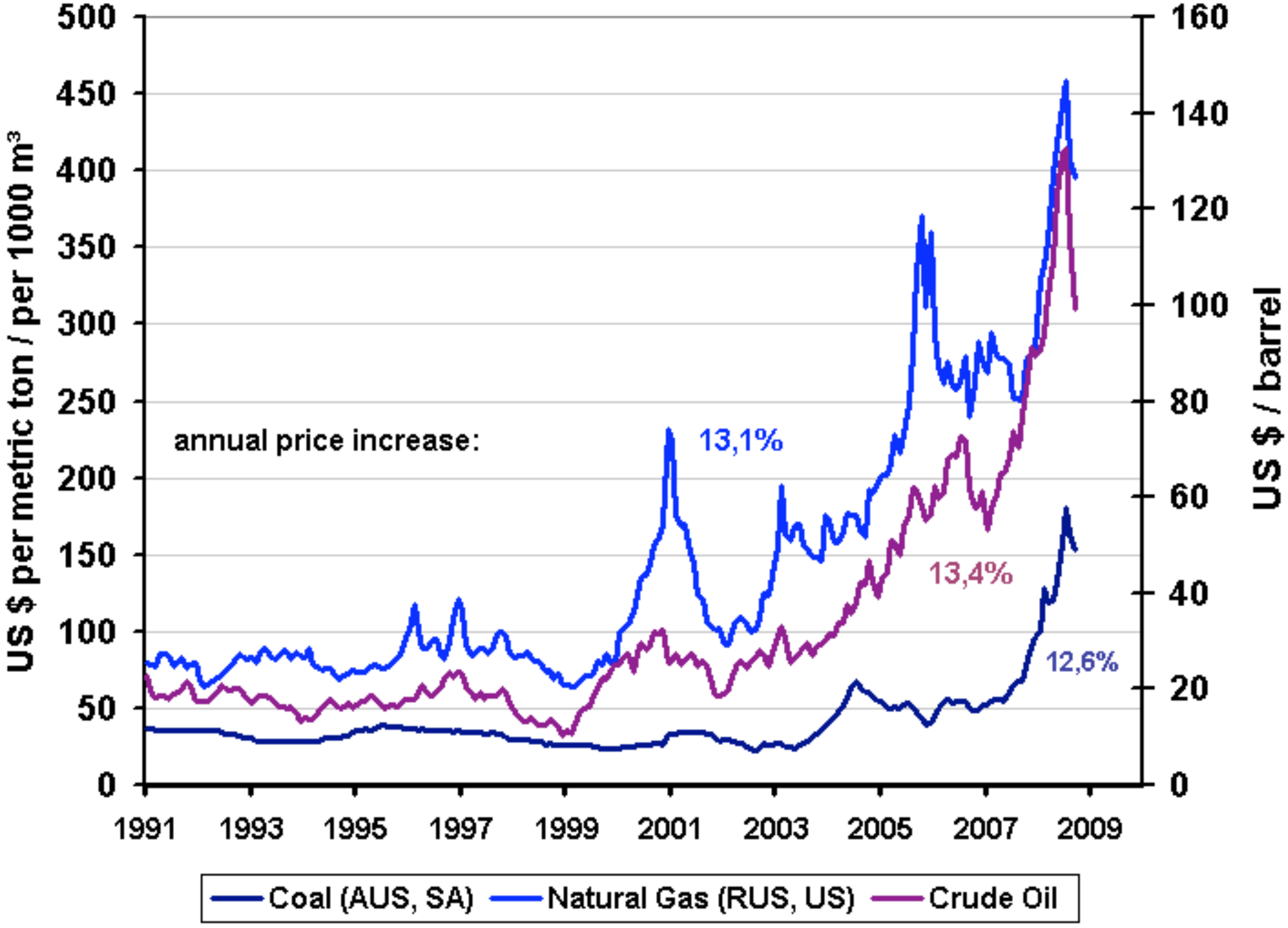


➔ 400ppm can be achieved by all models

➔ Different possibilities to reach low stabilisation

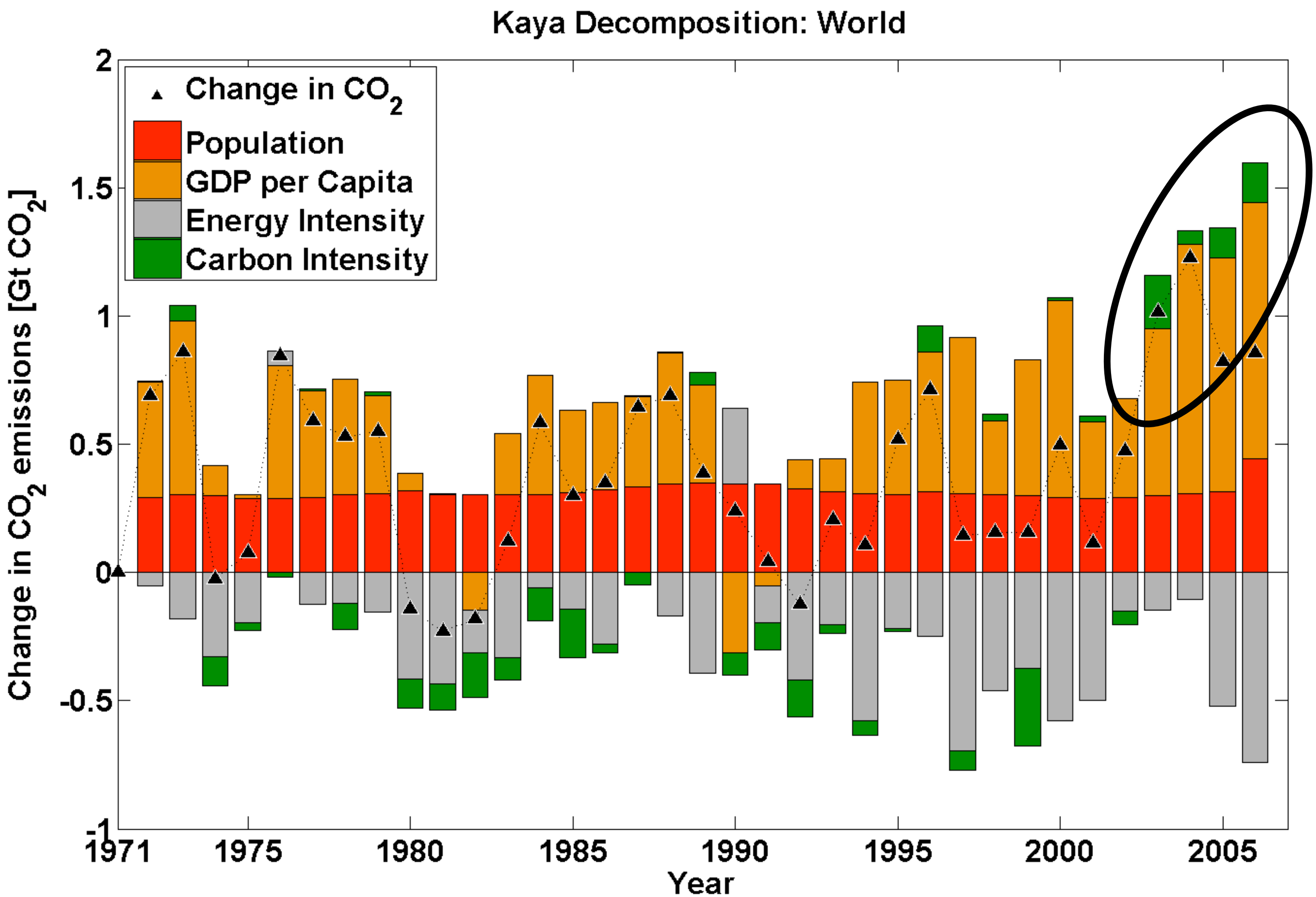
Knopf, Edenhofer et al. (2009)

Global Fossil Fuel Prices 1991 - 2008



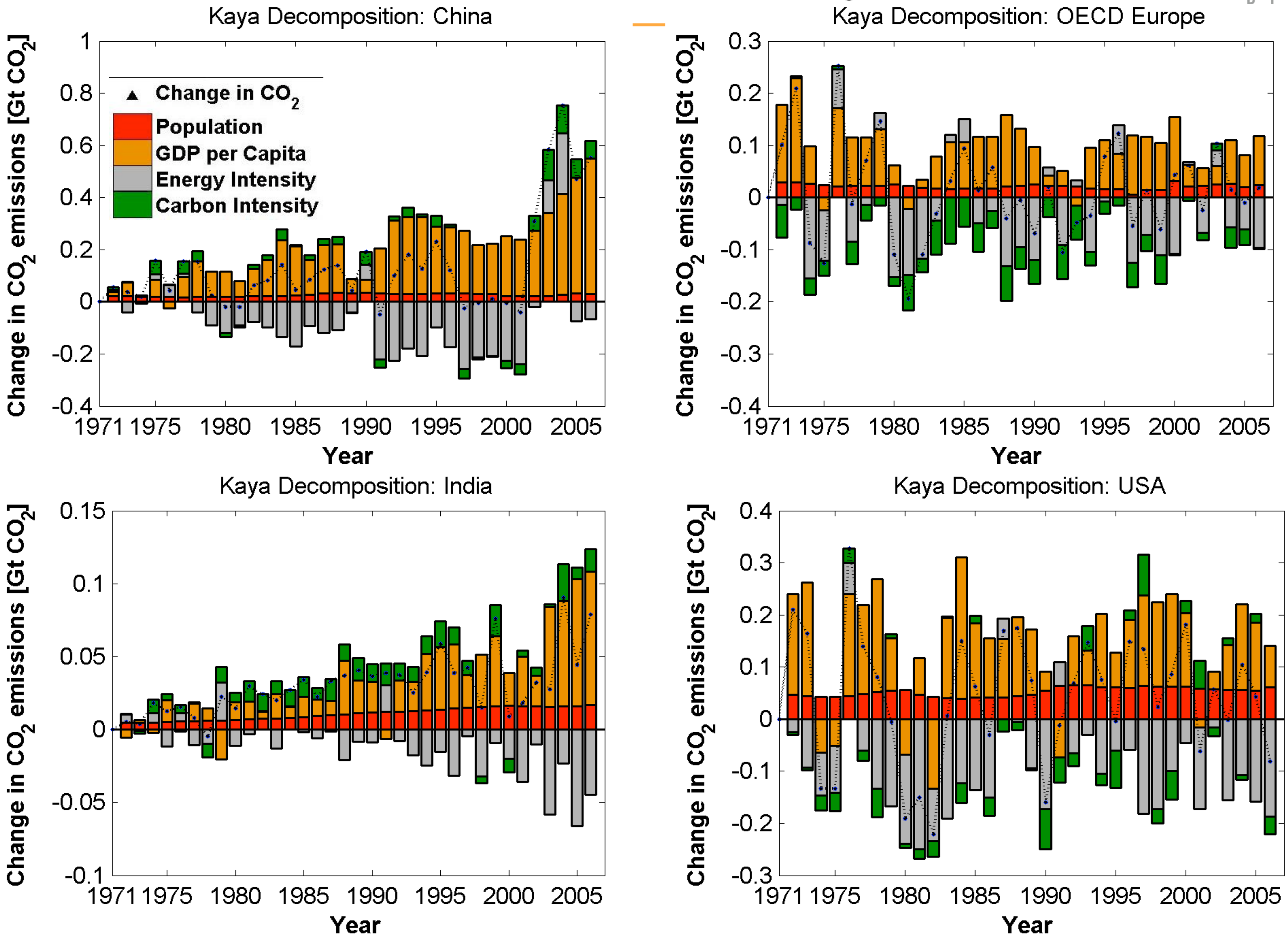
Source: IMF International Commodities Database

Renaissance of Coal



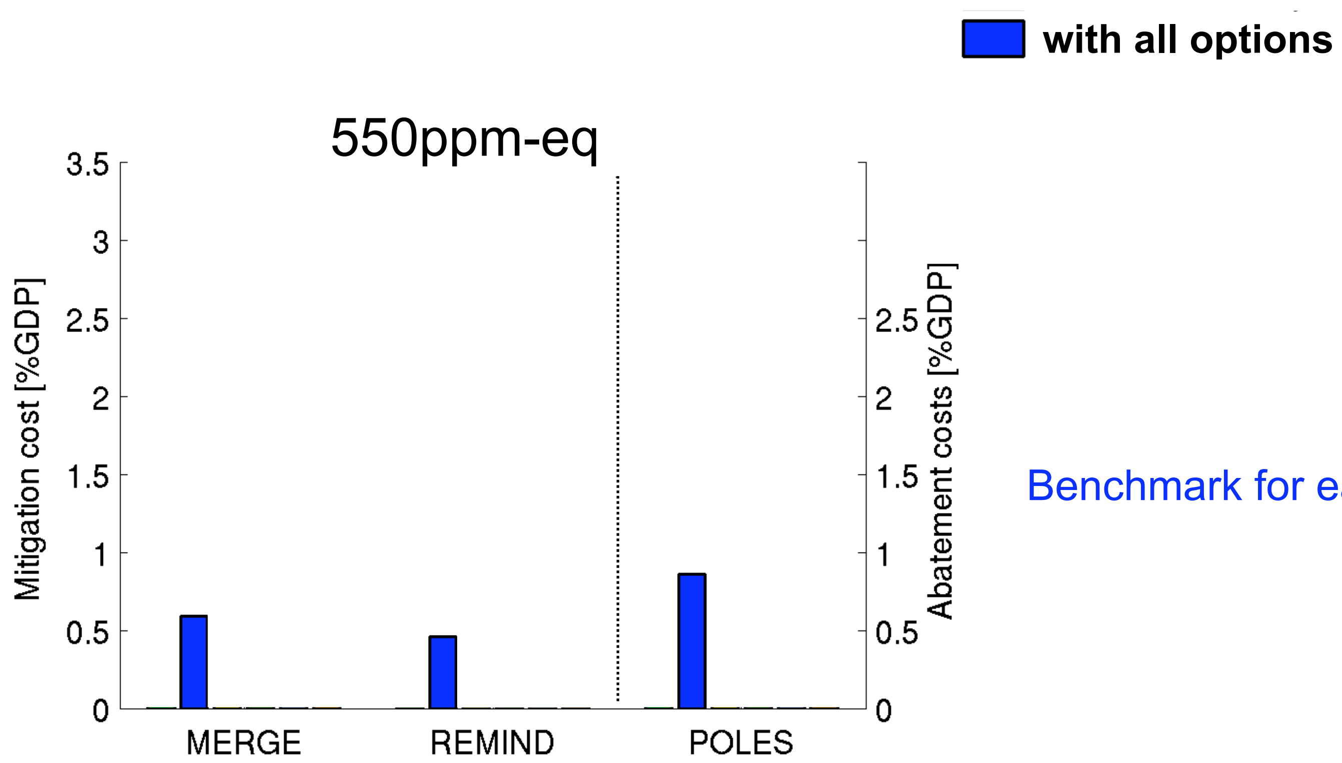
PIK 2009 (Jan Steckel)

Carbonization Pathways



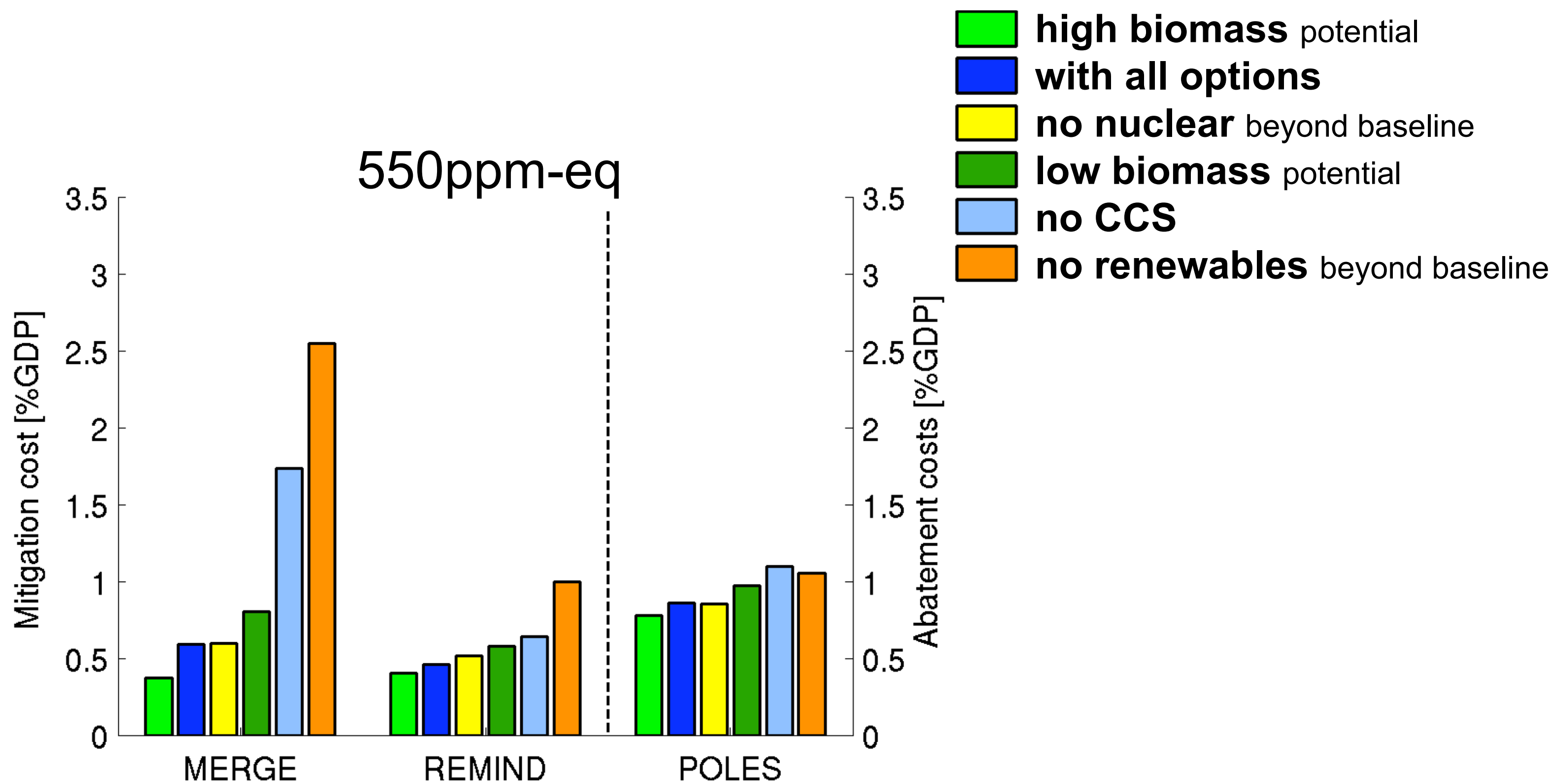
PIK 2009 (Jan Steckel)

Mitigation Costs: Technology Options, 550ppm



Benchmark for each model

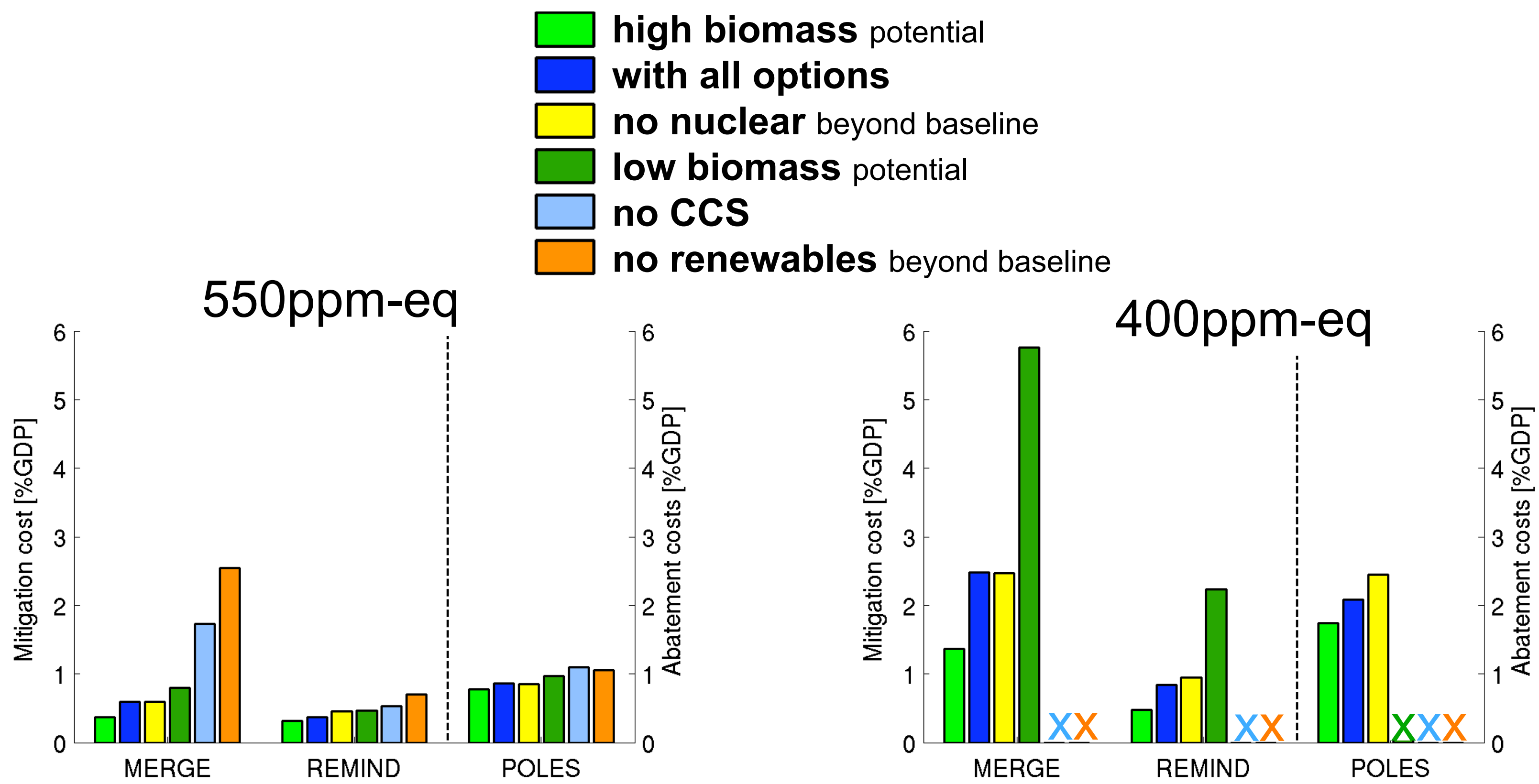
Mitigation Costs: Technology Options, 550ppm



Knopf, Edenhofer et al. 2009

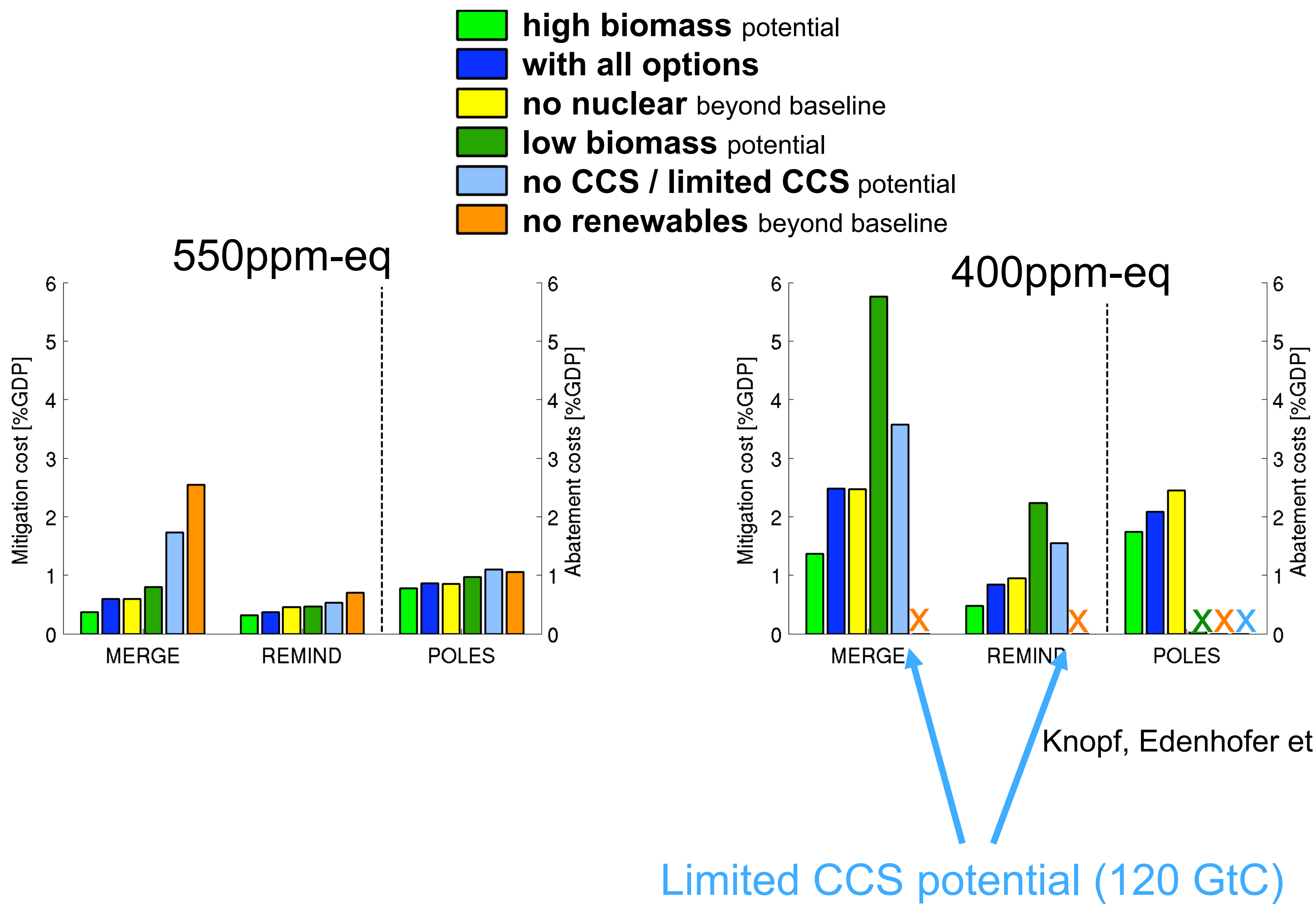
➔ Renewables and CCS are the most important options
➔ Ranking of options: Robust picture throughout all models

Technology Options for Low Stabilization



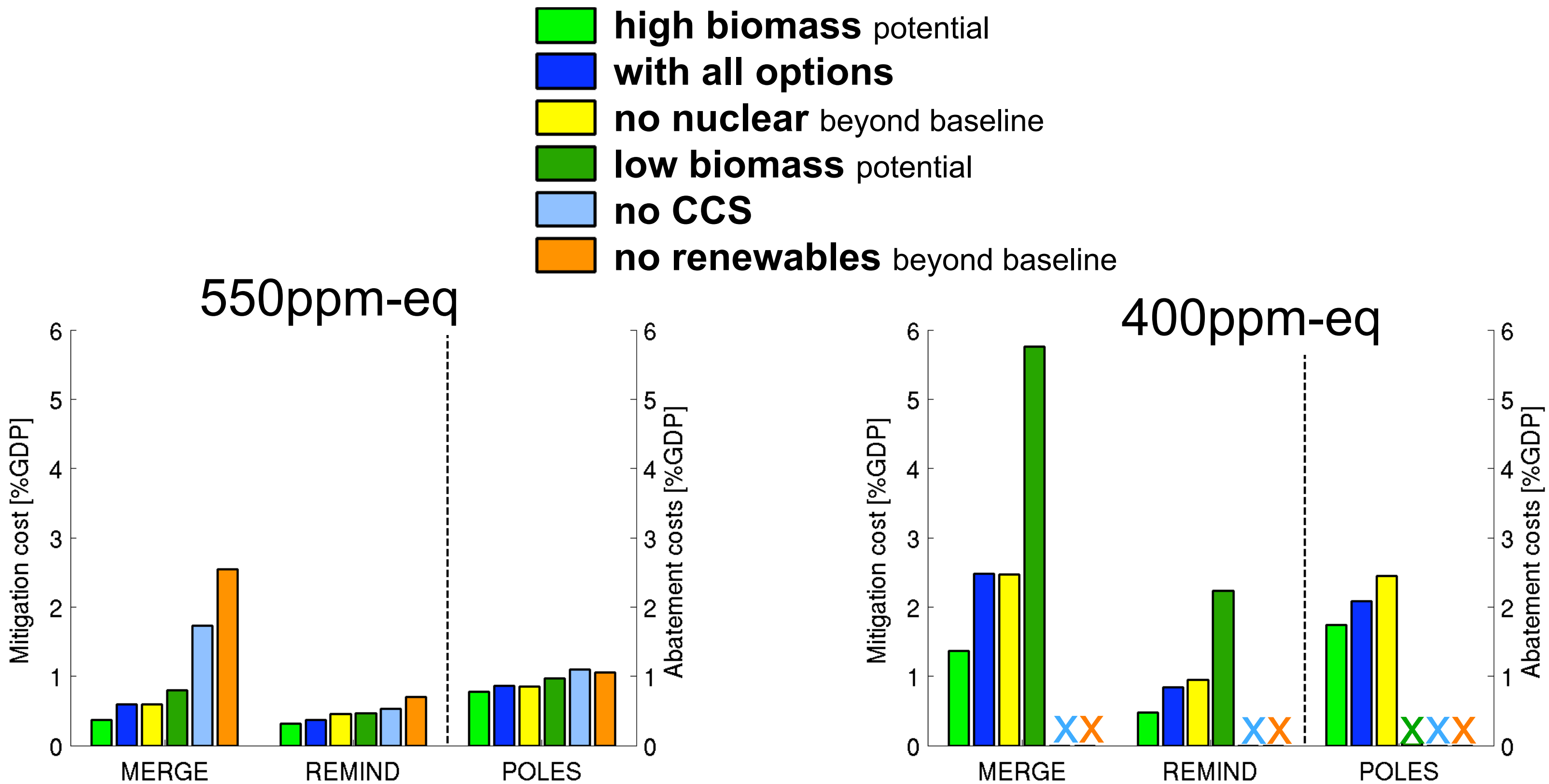
Knopf, Edenhofer et al. 2009

Technology Options for Low Stabilization



Knopf, Edenhofer et al. 2009

Technology Options for Low Stabilization



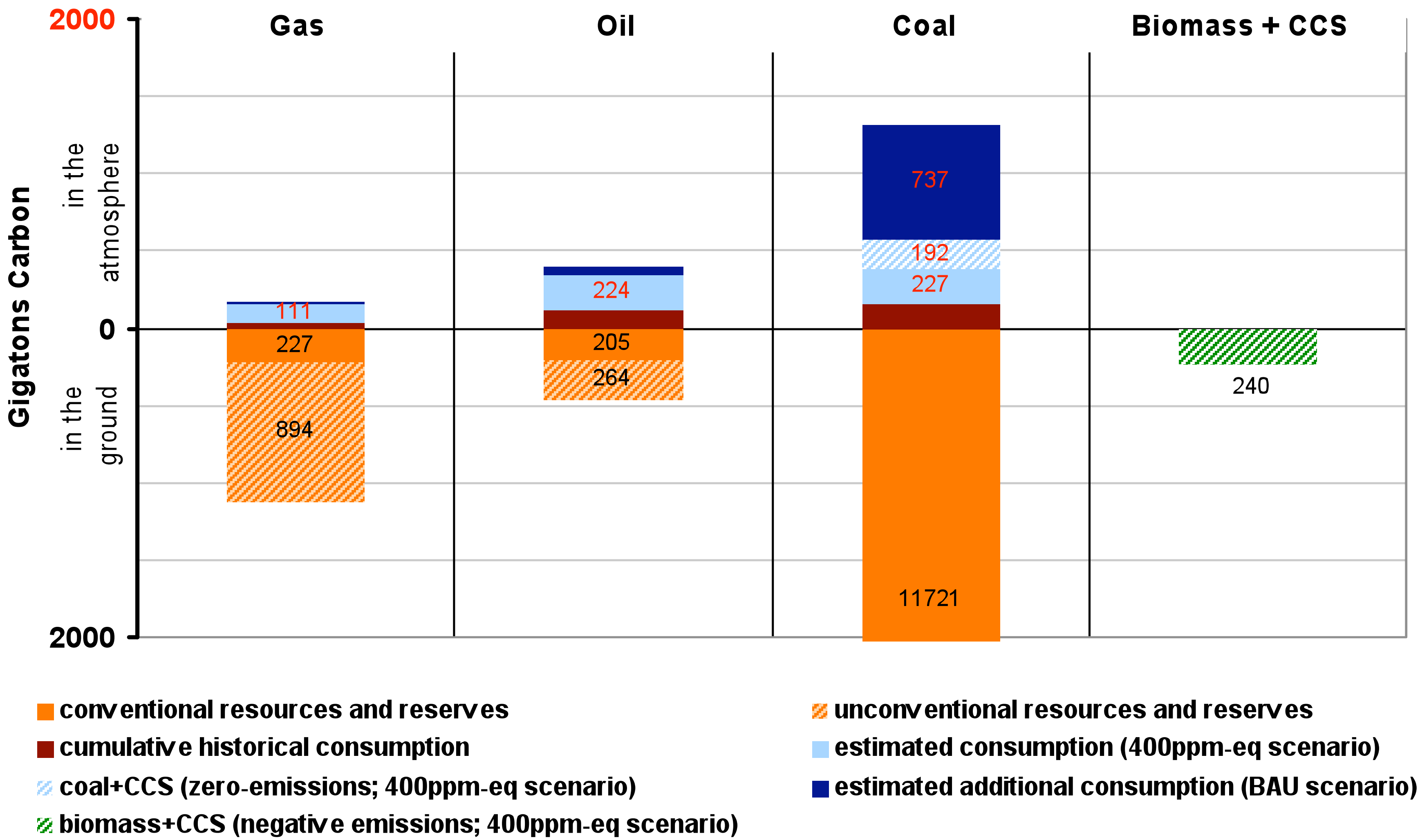
Knopf, Edenhofer et al. 2009

➔ 400 ppm neither achievable without CCS nor without extension of renewables

➔ Biomass potential dominates the mitigation costs of low stabilisation

➔ Nuclear is not important beyond its (high) use in the baseline

The Neglected Supply Side



Edenhofer, Kalkuhl (2009)

References

- Edenhofer, Knopf, Leimbach, Bauer (Eds.): A Special Issue in the Energy Journal on *The economics of low stabilisation* (2009)
- B. Knopf, O. Edenhofer, T. Barker, N. Bauer, L. Baumstark, B. Chateau, P. Criqui, A. Held, M. Isaac, M. Jakob, E. Jochem, A. Kitous, S. Kypreos, M. Leimbach, B. Magné, S. Mima, W. Schade, S. Scrieciu, H. Turton, D. van Vuuren (2009) The economics of low stabilisation: implications for technological change and policy. In M. Hulme, H. Neufeldt (Eds) Making climate change work for us – ADAM synthesis book, Cambridge University Press.
- Füssel, H.-M. (2007): in "A Global Contract on Climate Change“ by O. Edenhofer, G. Luderer, C. Flachsland and H.-M. Füssel, http://www.pik-potsdam.de/members/edenh/publications-1/contract-08-full