On the Economics of Renewables

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Global Commons and Climate Change

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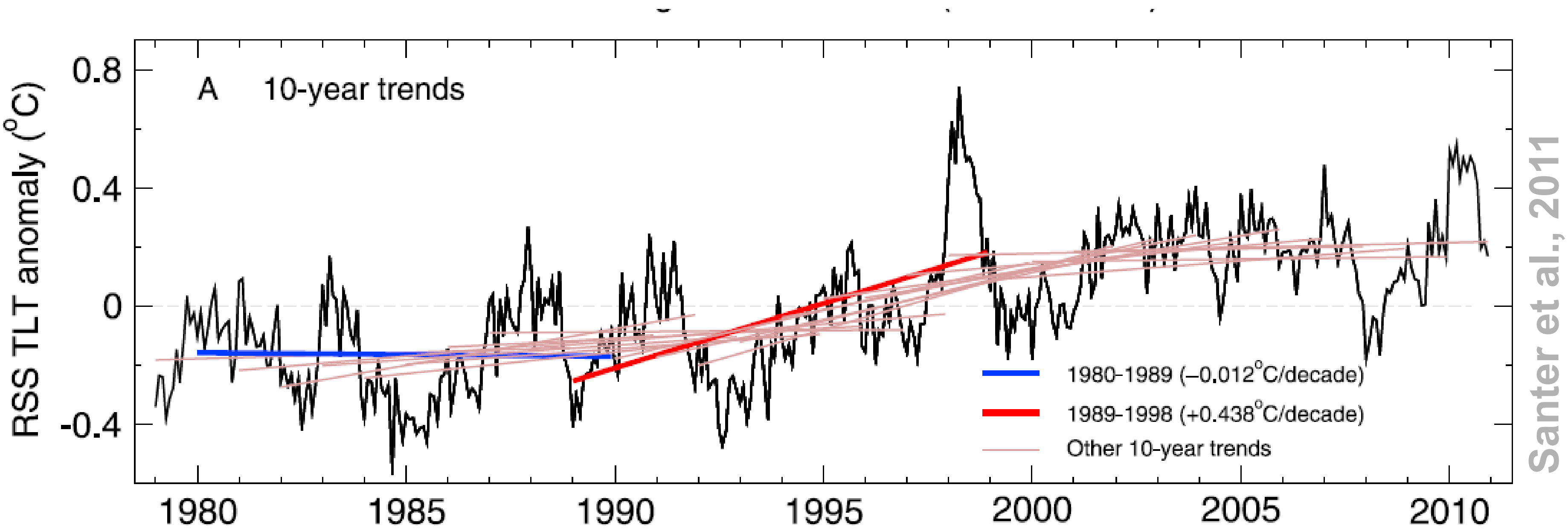
INTERGOVERNMENTAL PANEL ON climate change
WMO UNEP
Working Group III (WG III) – Mitigation of Climate Change

Overview

1. Has global warming stopped?
2. Scope of the challenge
3. The role of renewables in mitigation scenarios
4. System integration from a technical perspective
5. System integration from a cost perspective
6. System integration from a market perspective
7. How to cure market failures

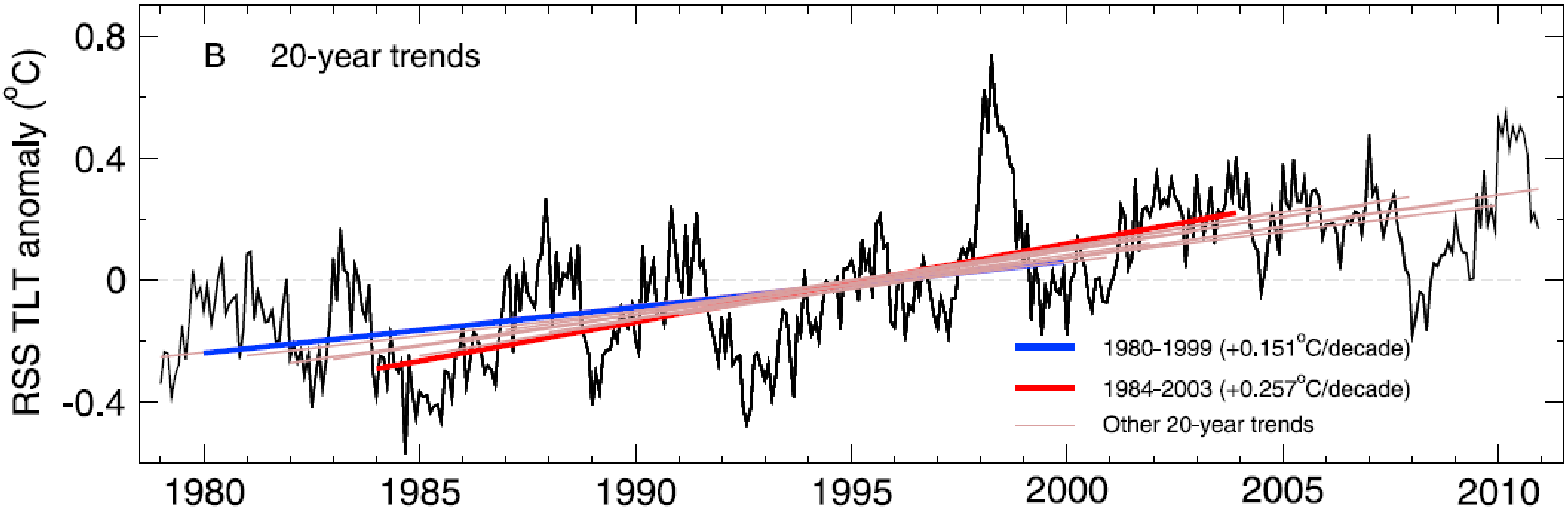
1. HAS GLOBAL WARMING STOPPED?

Has global warming stopped?



- Looking at last 10 years, global warming seems to have slowed down or even stopped
- Has the IPCC made a major mistake?
- Is global warming real?

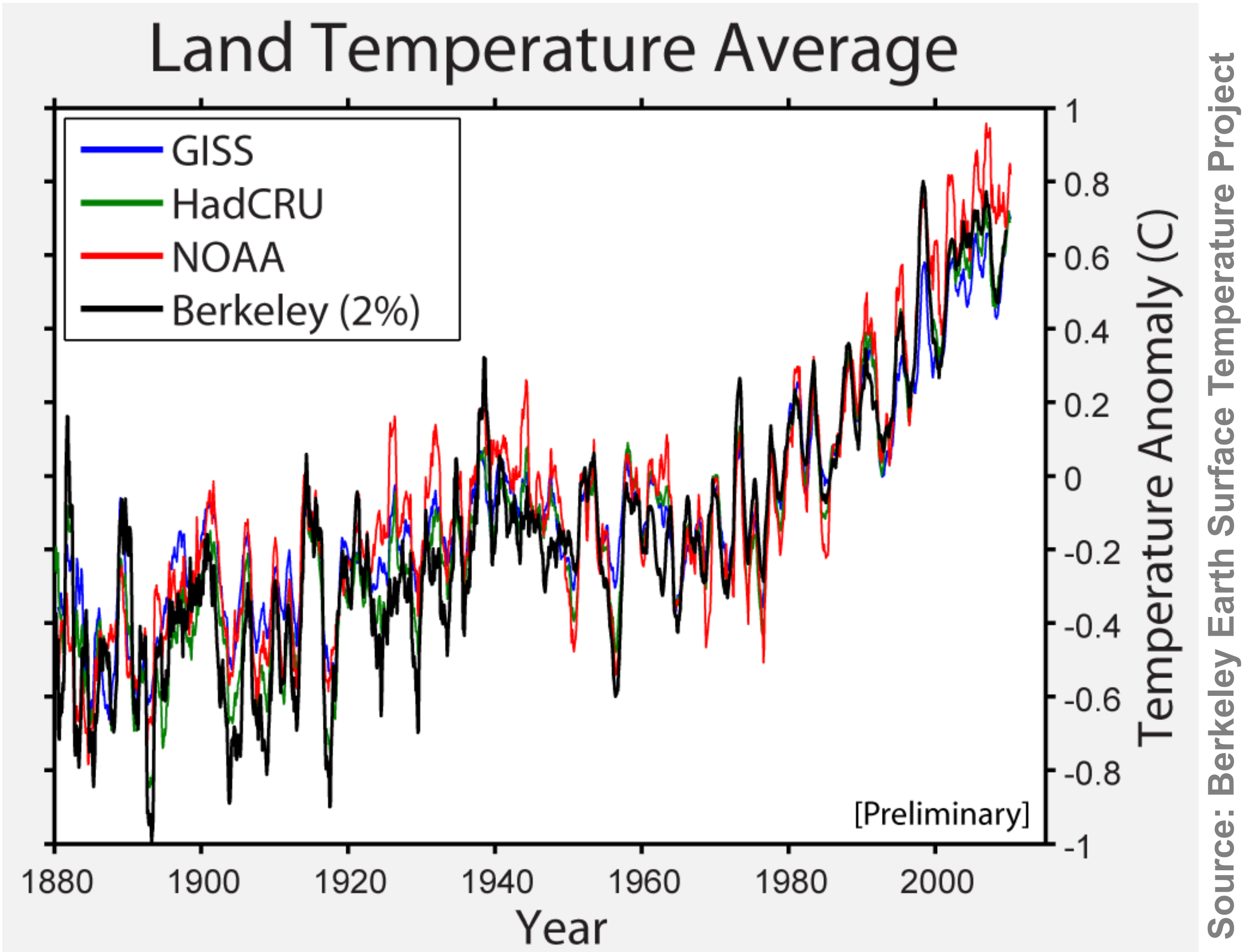
The influence of cutting the data!



Santer et al., 2011

- Multiple reasons for stable temperatures last decade:
  - “Slow down” last decades within natural variation
  - 1997/98 exceptionally warm due to El Nino
  - Cooling effect of increasing air pollution, particularly sulphur
    - *Temperatures likely to increase once clean air policies are commissioned also in newly industrializing countries*
- Looking at longer trends makes obvious that global warming has not stopped at all

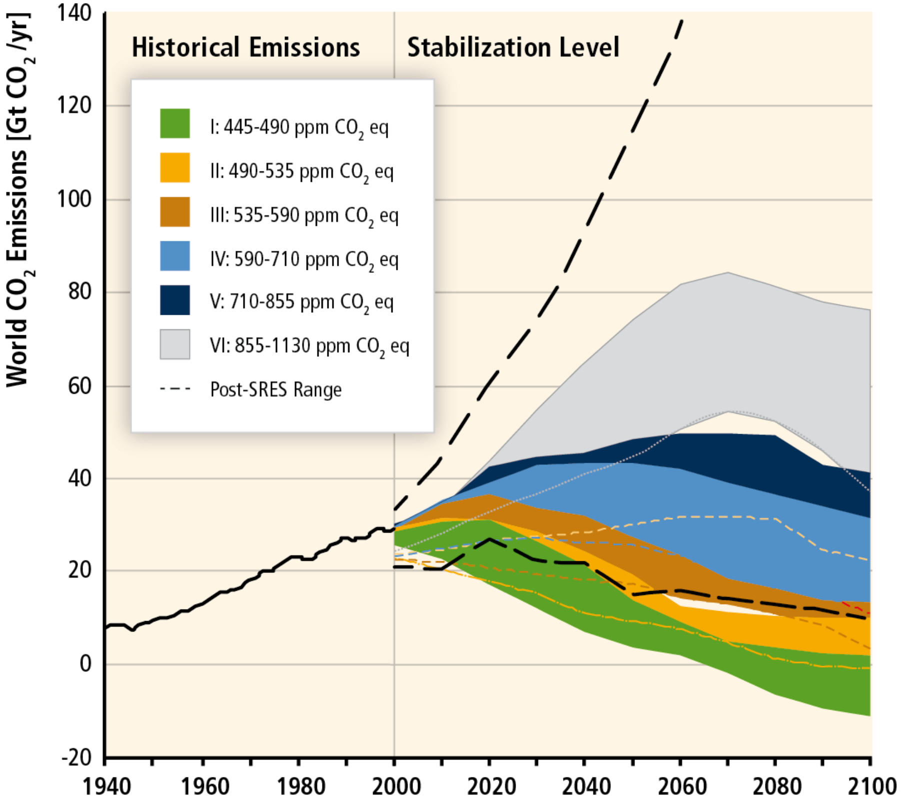
Long term trends show clear evidence

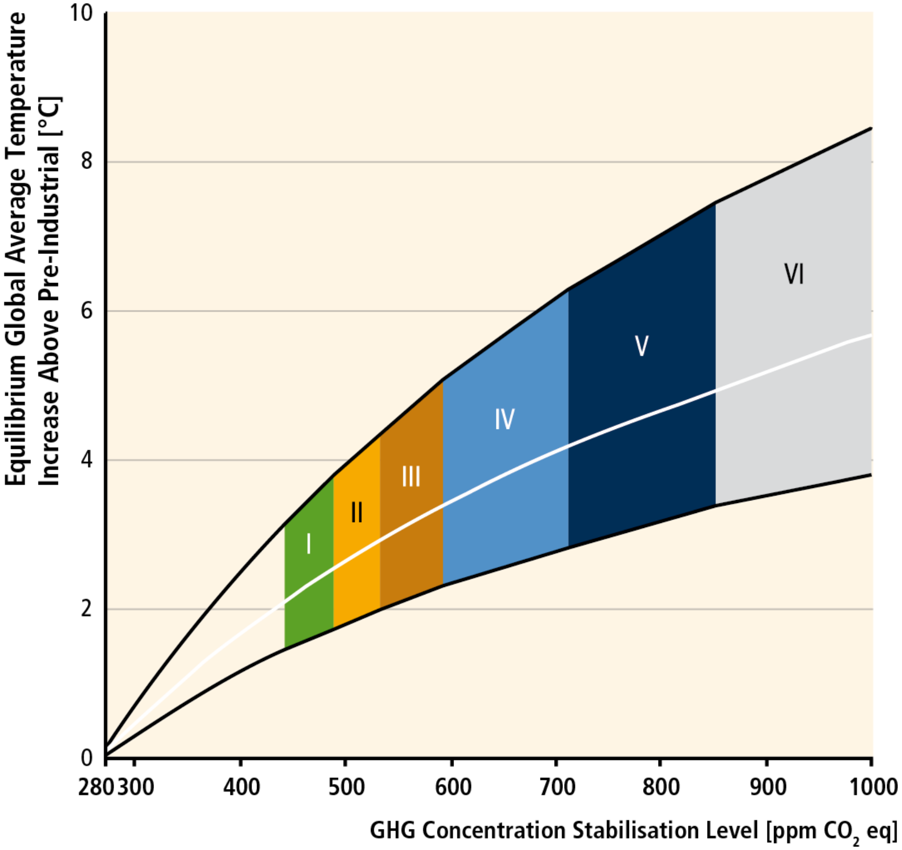


- Temporal slow downs of global warming have occurred already in the past
- Recent independent examination of IPCC results (Berkeley Earth Surface Temperature Project) has confirmed results

2. THE SCOPE OF THE CHALLENGE

Climate Policy as an Insurance

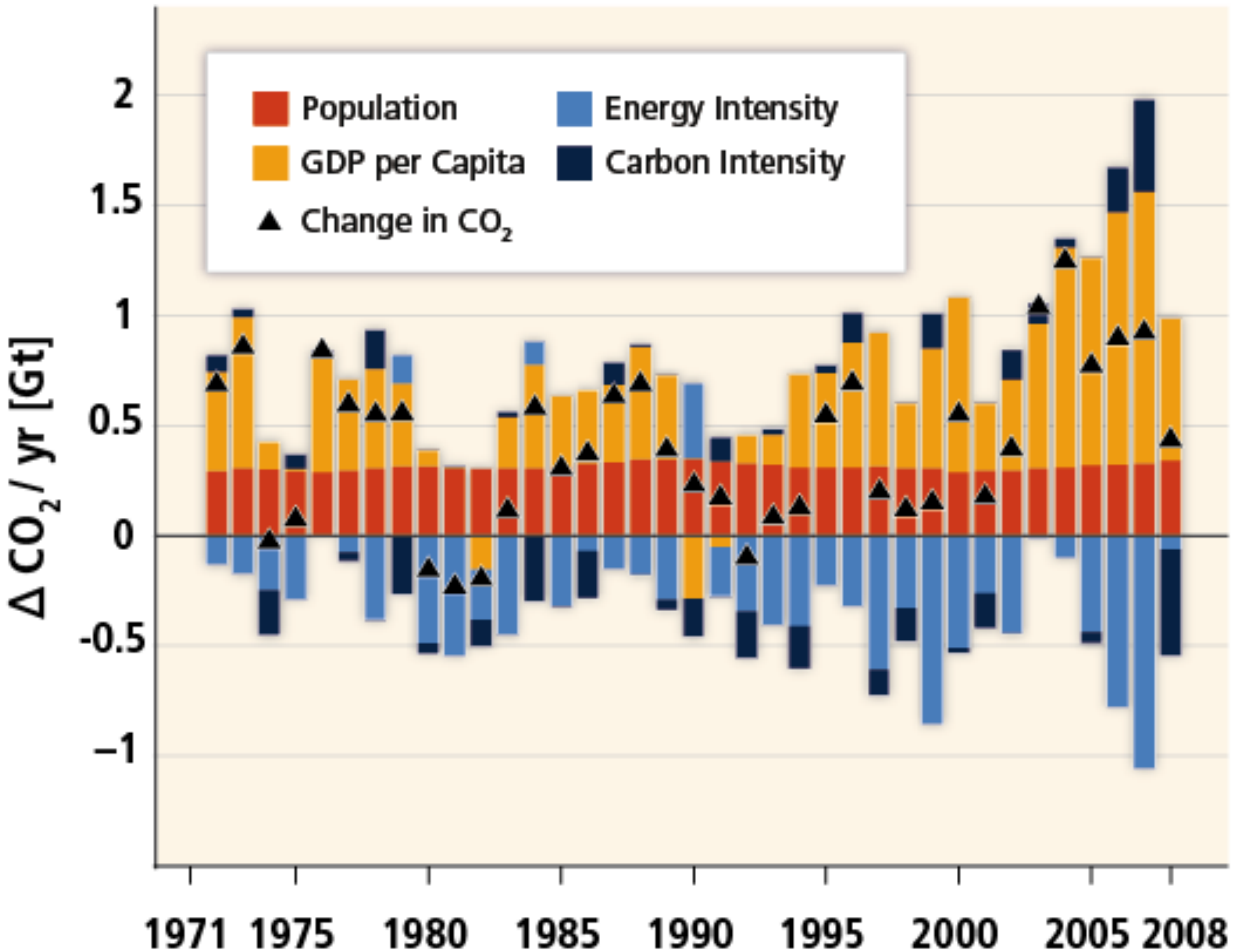




GHG emissions resulting from the provision of energy services contribute significantly to the increase in atmospheric GHG concentrations.

SRREN (IPCC, 2011)

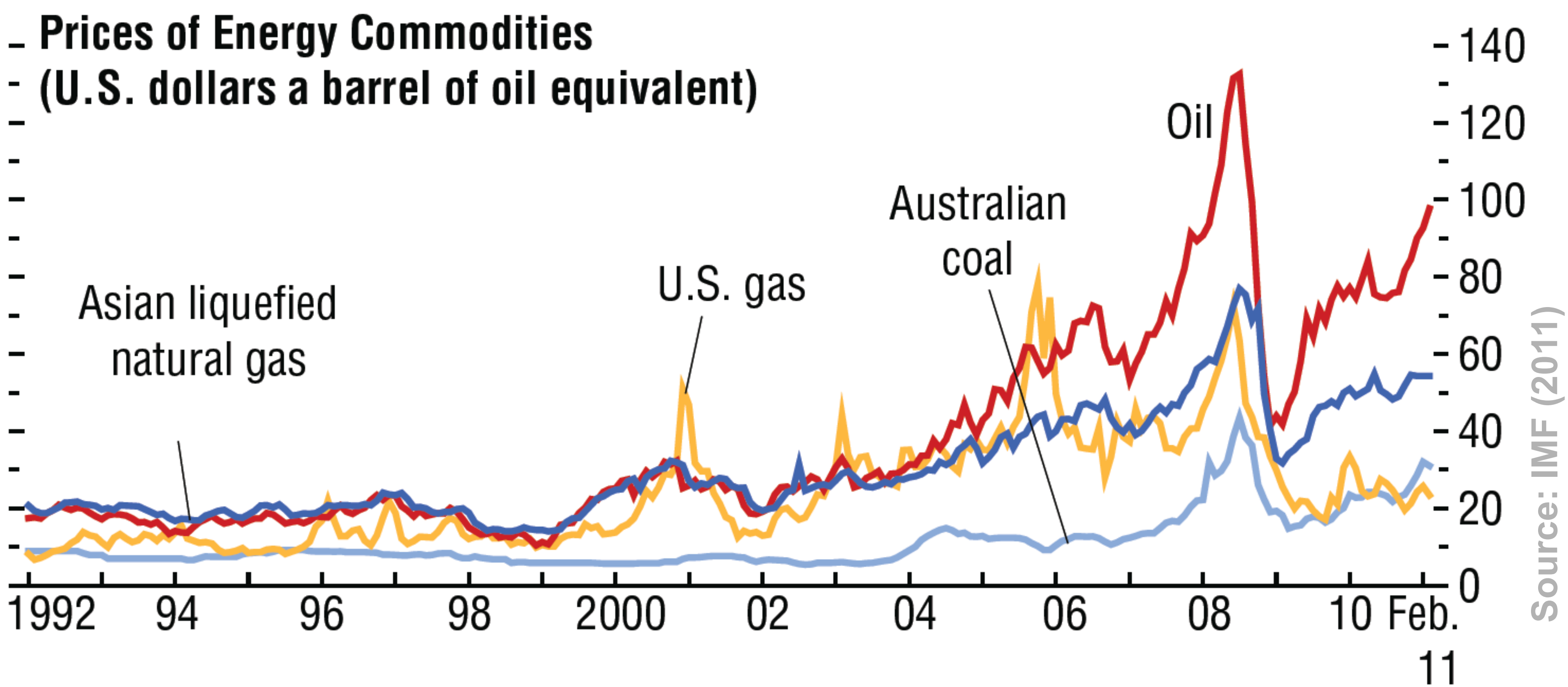
We are not on Track – Renaissance of Coal!



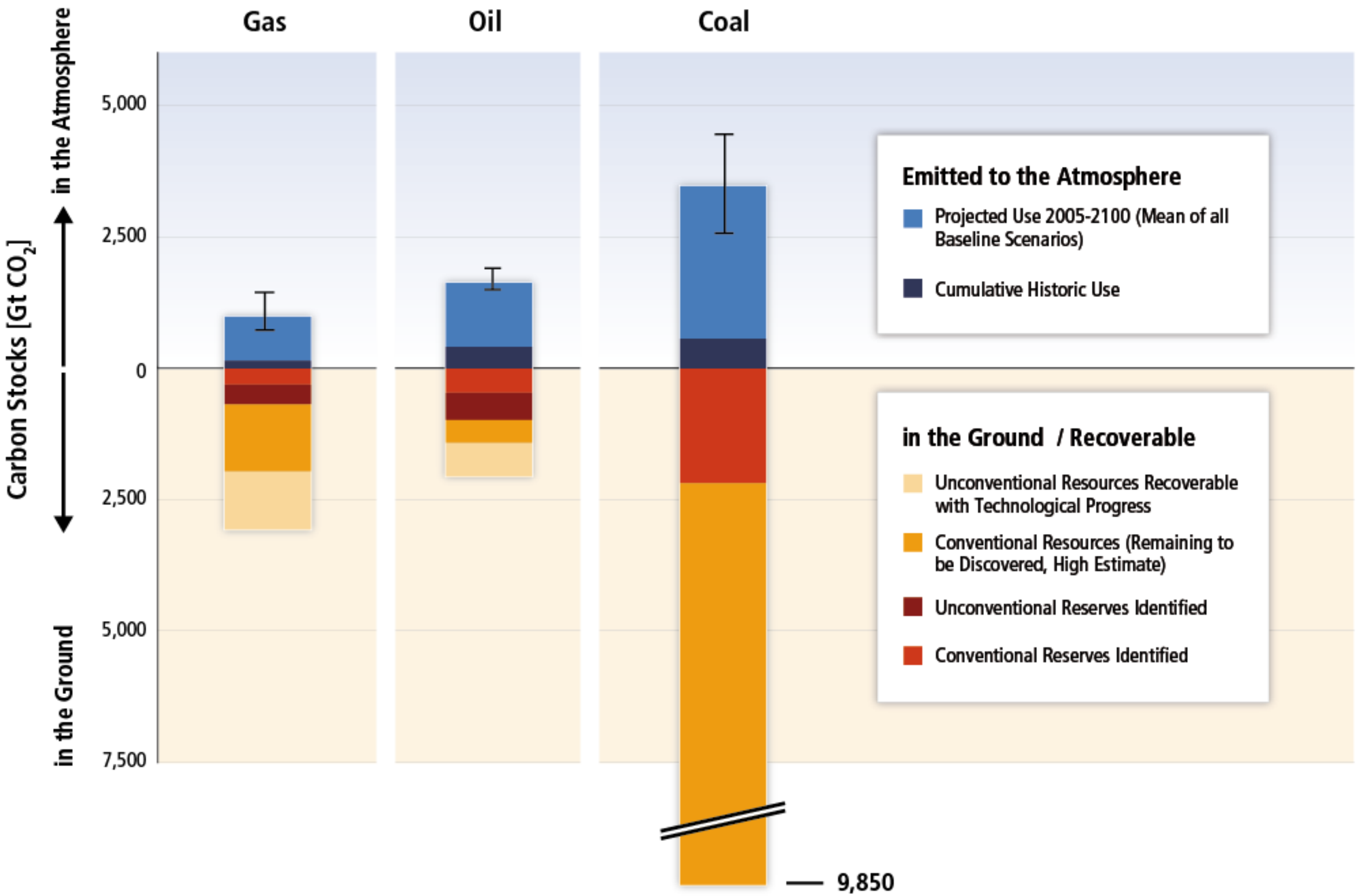
Kaya decomposition of global CO2 emissions.

SRREN (IPCC, 2011)

Renaissance of Coal?

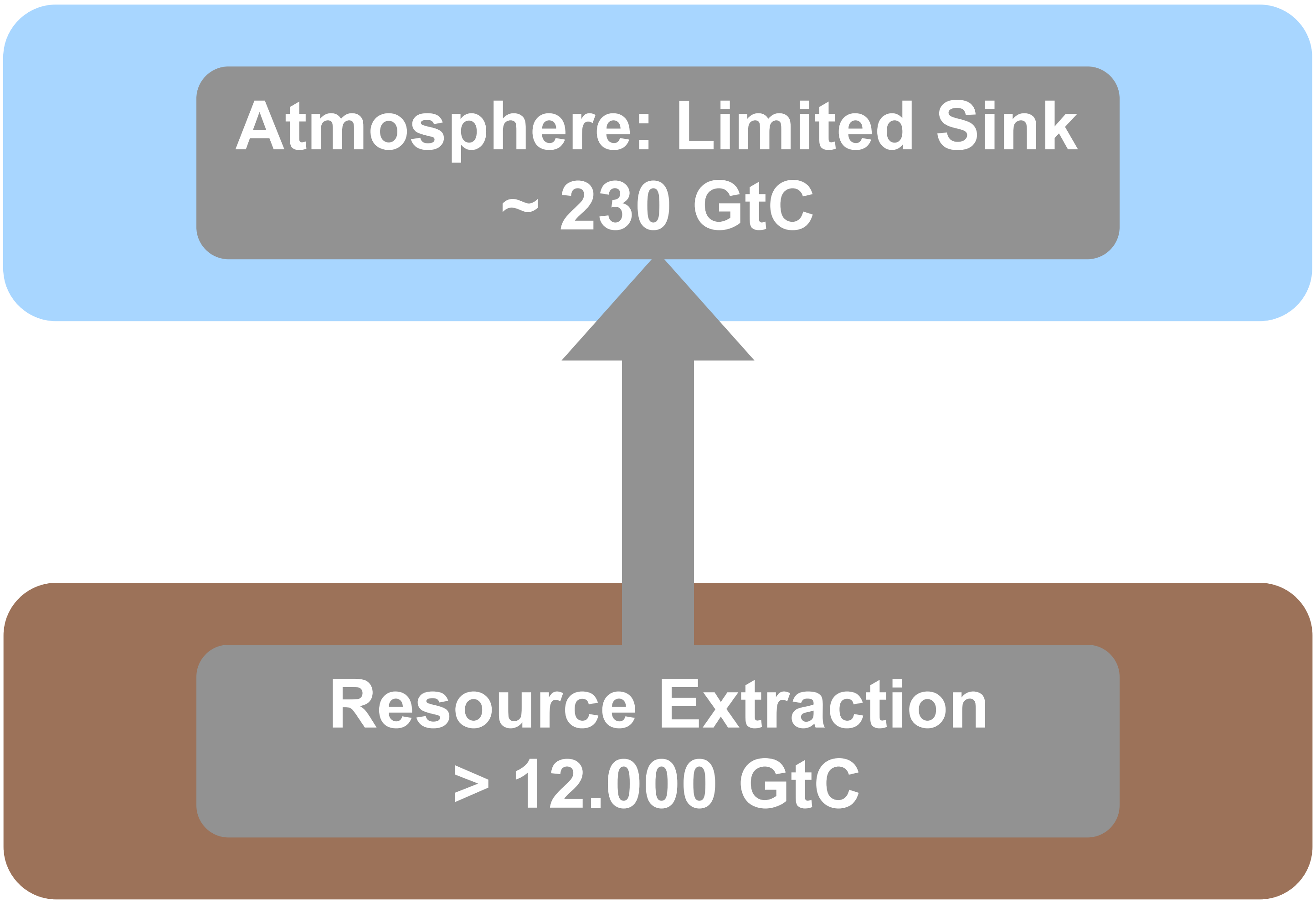


The BAU Scenarios could exceed the Level of Greenhouse Gas Concentration of 600ppm (~4°C Temperature Increase)



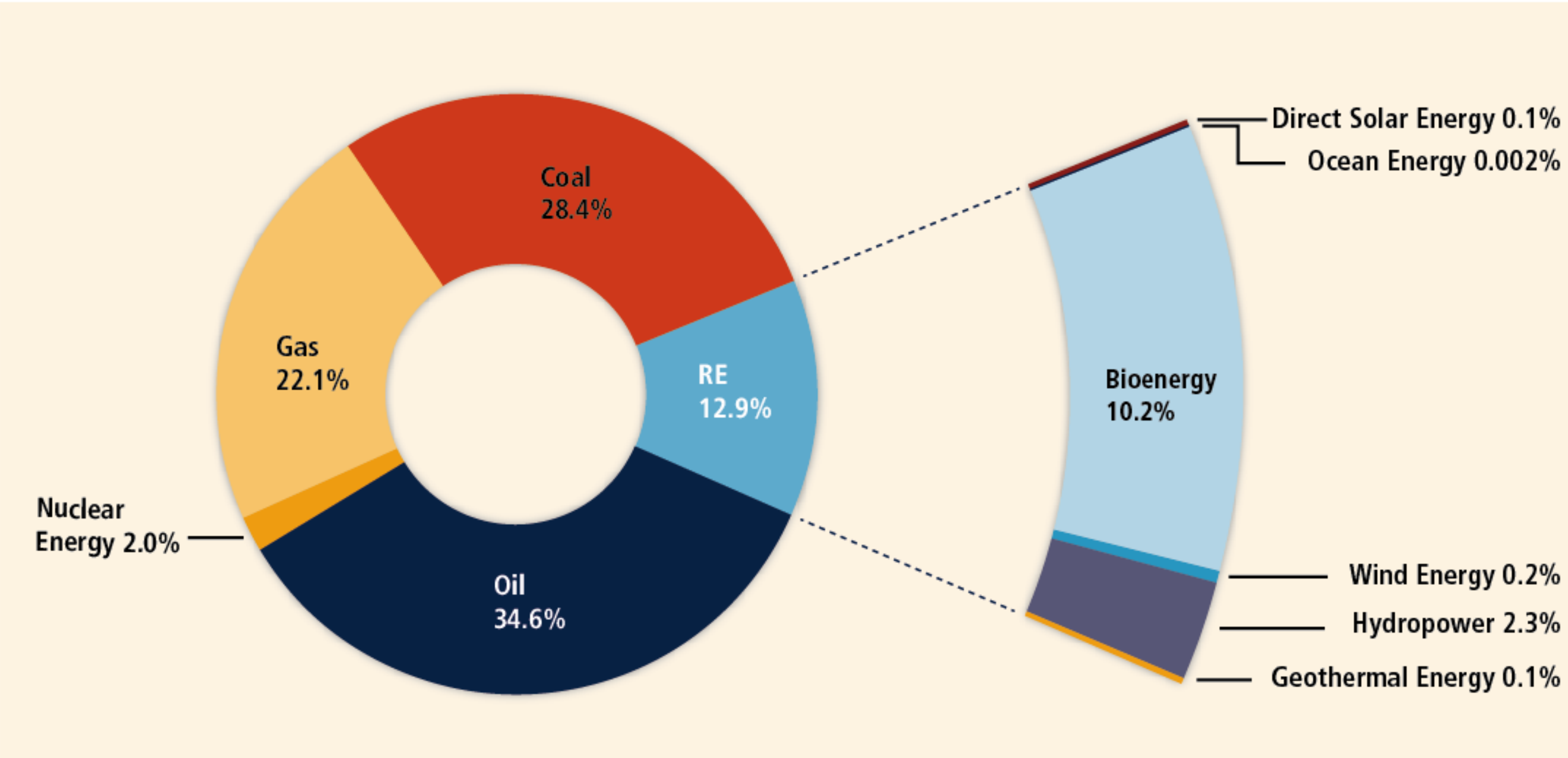
SRREN (IPCC, 2011)

The Atmosphere as a Global Common



3. THE ROLE OF RENEWABLES FOR MITIGATION

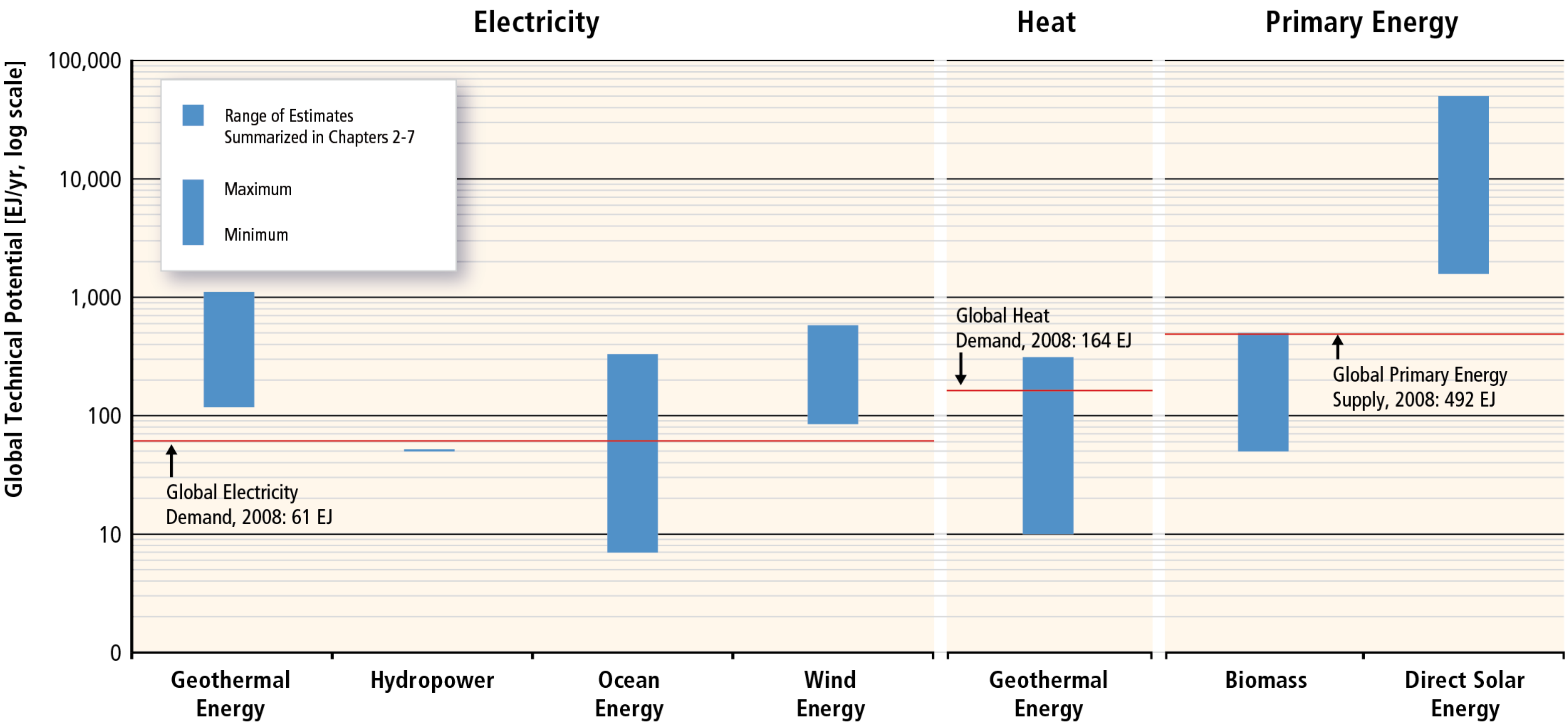
The Current Global Energy System is dominated by Fossil Fuels



Shares of energy sources in total global primary energy supply in 2008.

SRREN (IPCC, 2011)

The Technical Potential of Renewable Energies

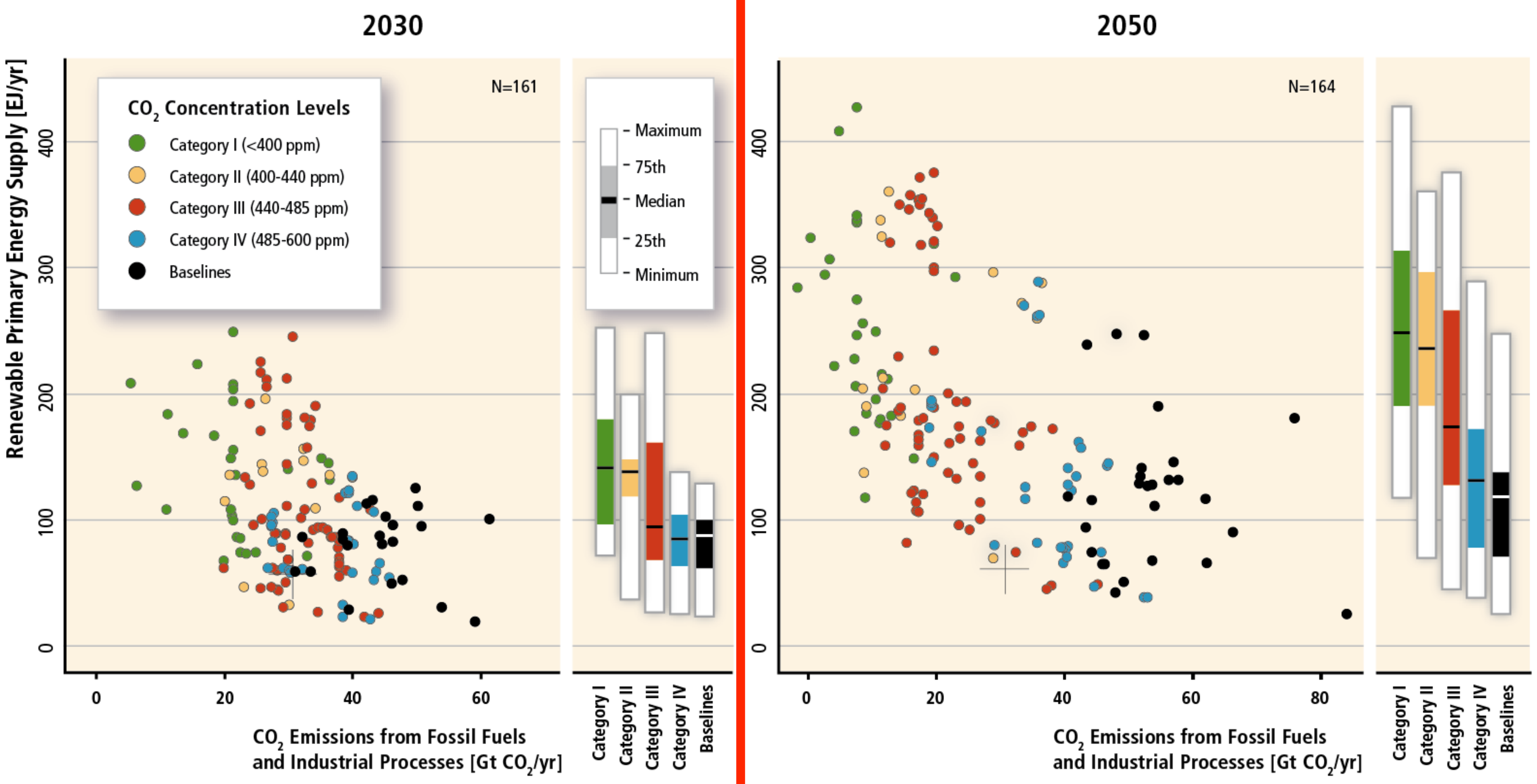


Range of Estimates of Global Technical Potentials

	Geothermal Energy	Hydropower	Ocean Energy	Wind Energy	Geothermal Energy	Biomass	Direct Solar Energy
Max (in EJ/yr)	1109	52	331	580	312	500	49837
Min (in EJ/yr)	118	50	7	85	10	50	1575

SRREN (IPCC, 2011)

Global RE Primary Energy Supply from 164 Long-Term Scenarios versus Fossil and Industrial CO_2 Emissions



SRREN SPM, Figure SPM.9

SRREN (IPCC, 2011)

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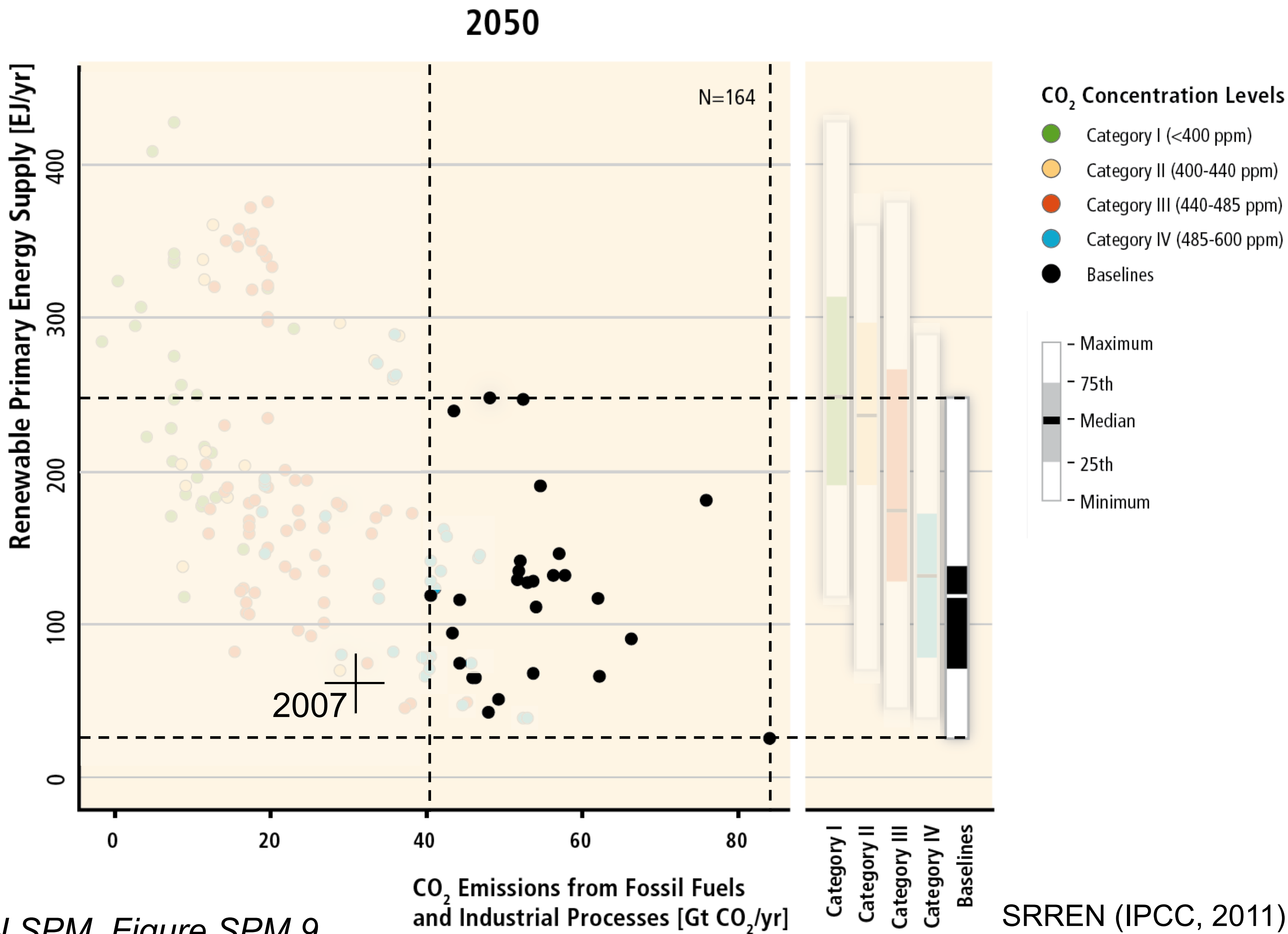

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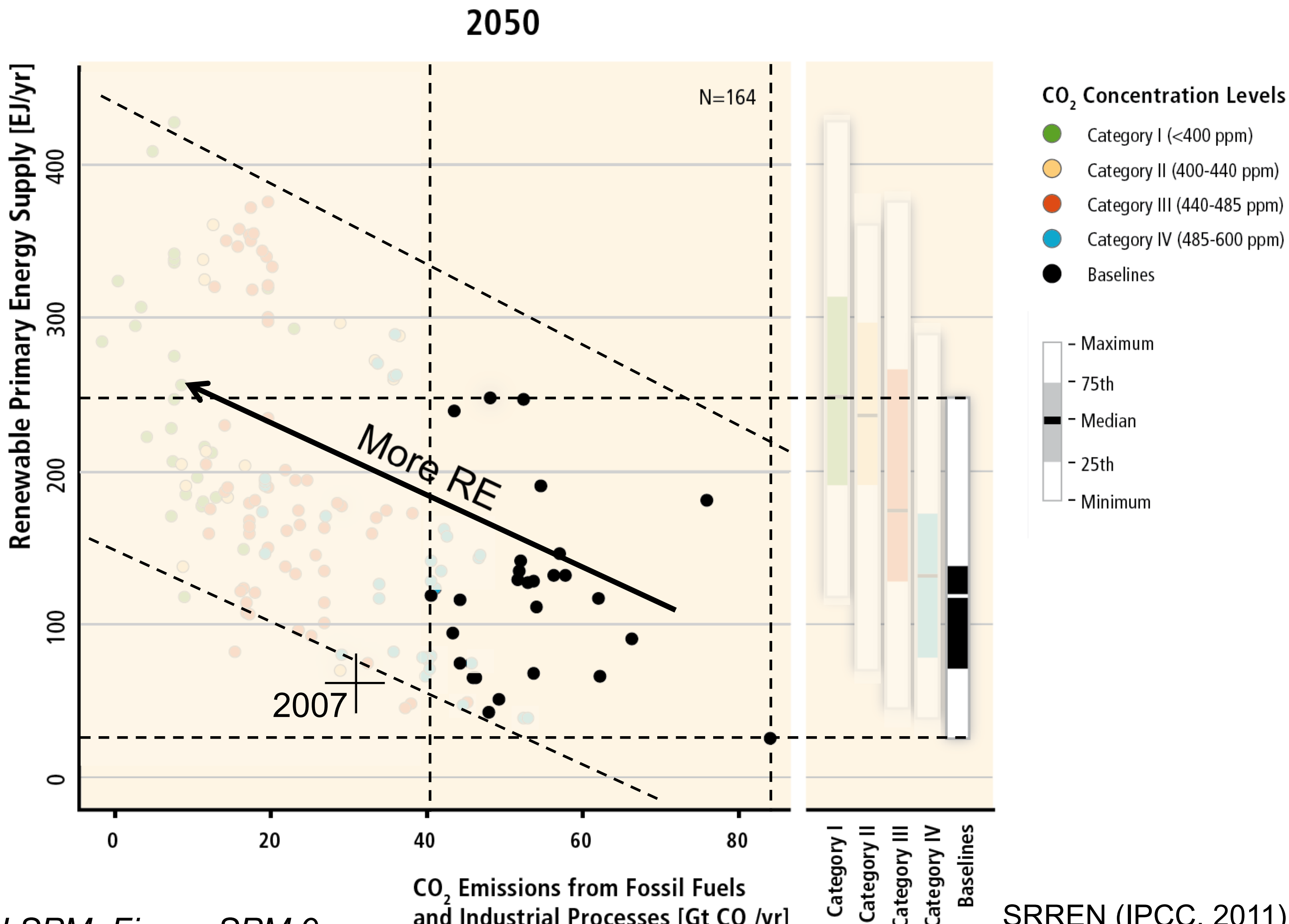
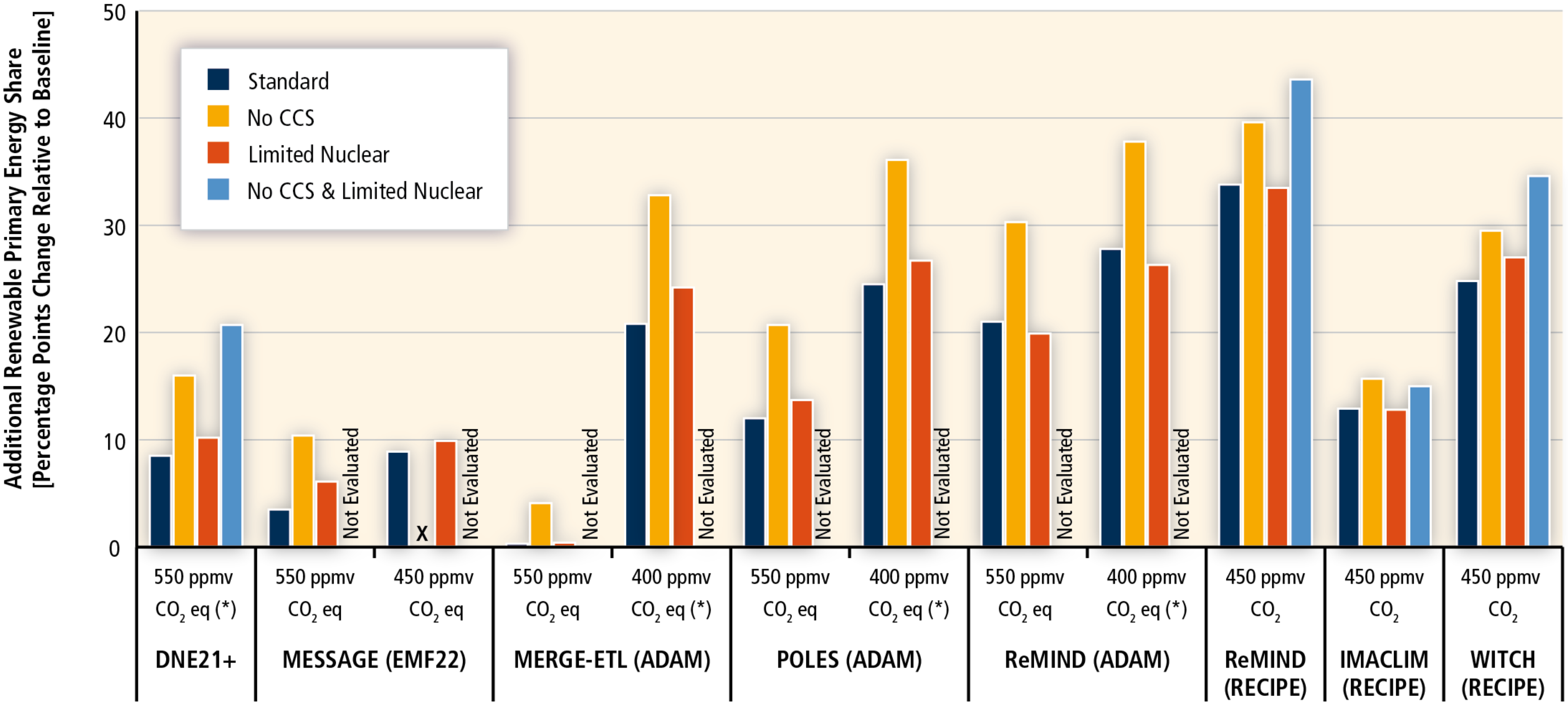


SRREN SPM, Figure SPM.9

SRREN (IPCC, 2011)

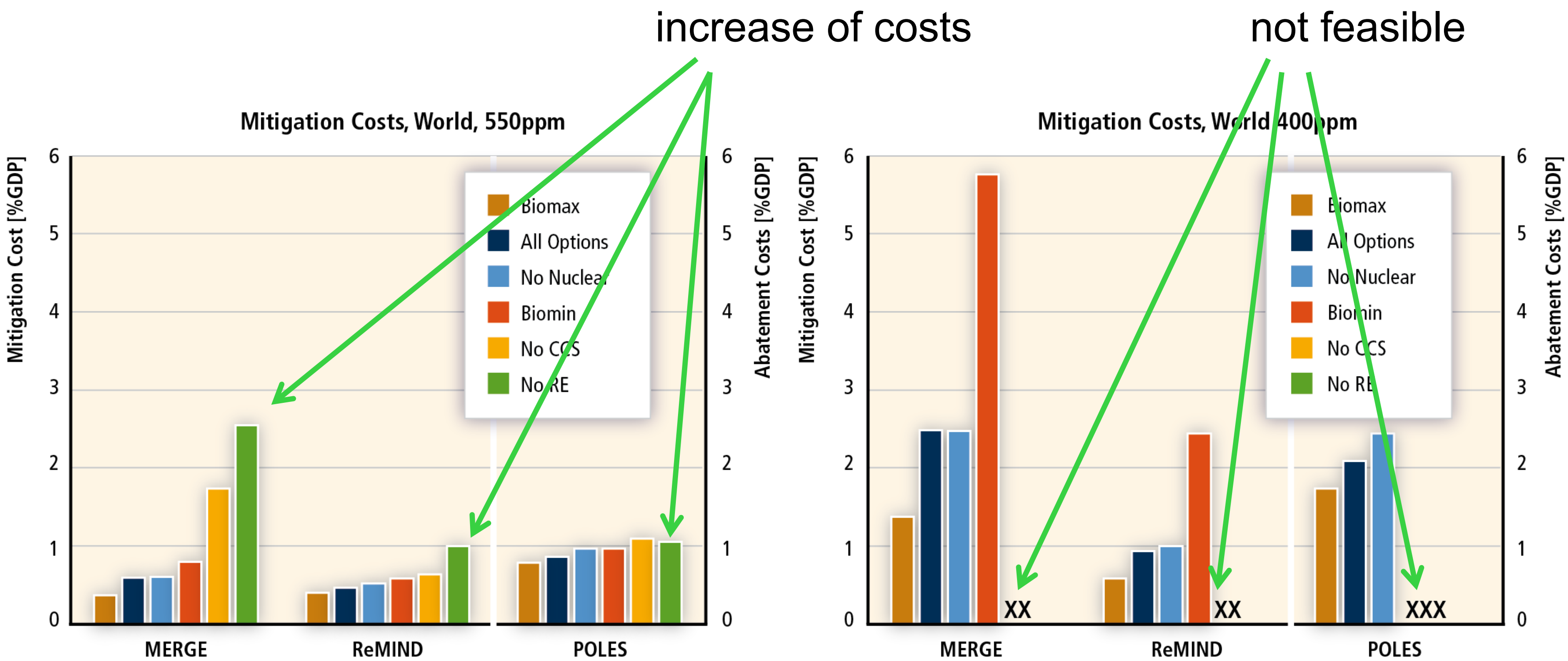
The Importance of RES depends on the Availability of other Options



IPCC 2011

- **Without the availability of CCS, Renewables become more important**

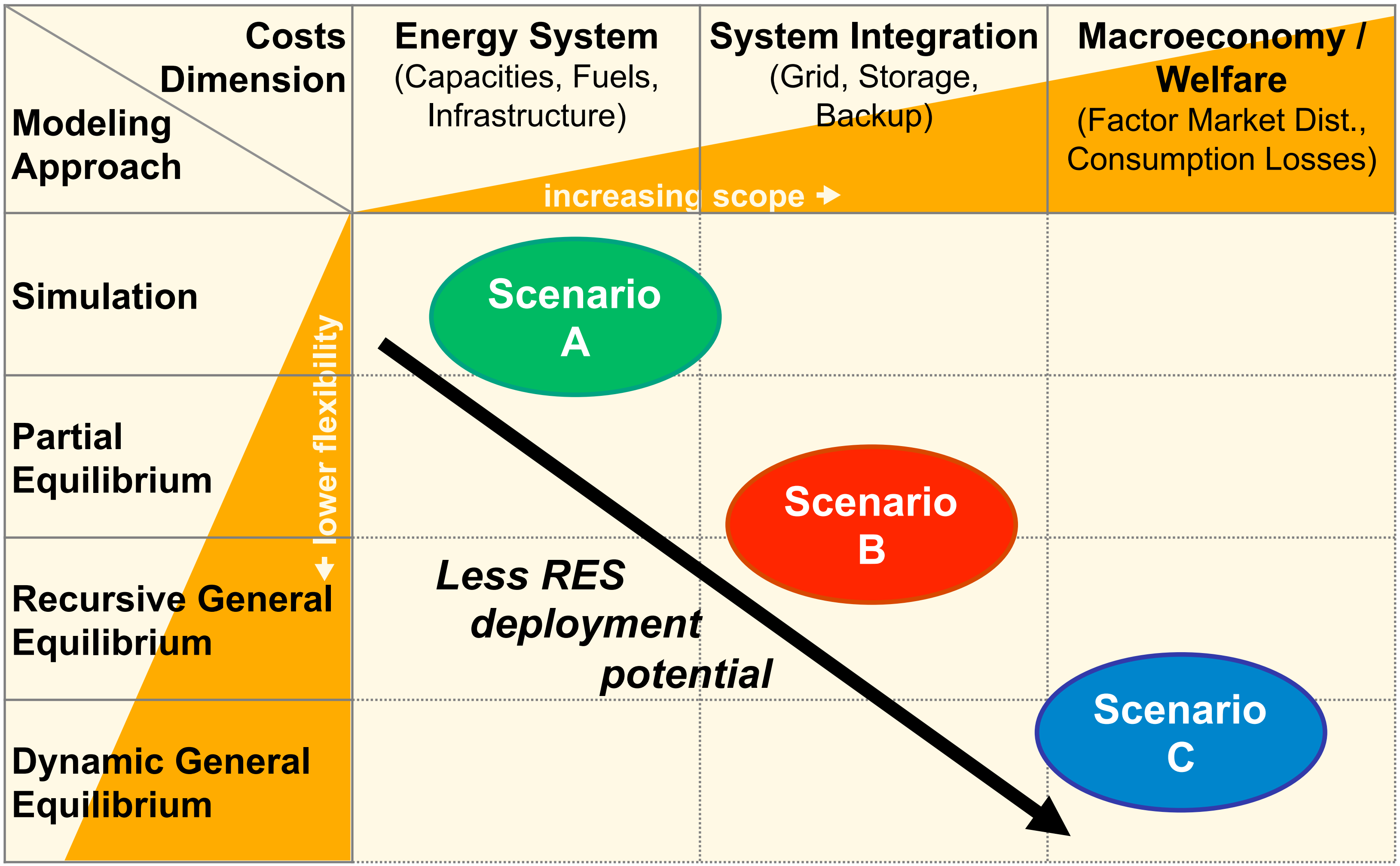
Macroeconomic Effect of Renewables



Edenhofer et al. 2010

- without further deployment of Renewables costs increase for medium climate targets…
- …and ambitious targets are not feasible any more

Scenario Classification Matrix



4. SYSTEM INTEGRATION FORM A TECHNICAL PERSPECTIVE

Numerical Limitations of Integrated Assessment Models

Time resolution:
Time steps of several years

→ Fluctuations of
renewables neglected

Geographical resolution:
Aggregate world regions

→ Infrastructure
neglected (e.g. grids)

Technological challenge
with large shares of fluctuating renewables:

The electricity grid requires an
exact match of supply and demand
at **any time** and at **any place**.

Integration characteristics for a selection of RE electricity generation technologies

Technology		Plant size range	Variability: Characteristic time scales for power system operation	Dispatchability	Geographical diversity potential	Predictability	Capacity factor range	Capacity credit range	Active power, frequency control	Voltage, reactive power control
		(MW)	Time scale	See legend	See legend	See legend	%	%	See legend	See legend
Bioenergy		0.1–100	Seasons (depending on biomass availability)	+++	+	++	50–90	Similar to thermal and CHP	++	++
Direct solar energy	PV	0.004–100 modular	Minutes to years	+	++	+	12–27	<25–75	+	+
	CSP with thermal storage*	50–250	Hours to years	++	+**	++	35–42	90	++	++
Geothermal energy		2–100	Years	+++	N/A	++	60–90	Similar to thermal	++	++
Hydropower	Run of river	0.1–1,500	Hours to years	++	+	++	20–95	0–90	++	++
	Reservoir	1–20,000	Days to years	+++	+	++	30–60	Similar to thermal	++	++
Ocean energy	Tidal range	0.1–300	Hours to days	+	+	++	22.5–28.5	<10	++	++
	Tidal current	1–200	Hours to days	+	+	++	19–60	10–20	+	++
	Wave	1–200	Minutes to years	+	++	+	22–31	16	+	+
Wind energy		5–300	Minutes to years	+	++	+	20–40 onshore, 30–45 offshore	5–40	+	++

* Assuming CSP system with 6 hours of thermal storage in US Southwest.

** In areas with Direct Normal Irradiation (DNI) > 2,000 kWh/m2/yr (7,200 MJ/m2/yr)

IPCC 2011

Capacity credit is an indicator for the reliability of a generation type to be available during peak demand hours.

Technology		[...]	Capacity credit range
		[...]	%
Bioenergy		[...]	Similar to thermal and CHP
Direct solar energy	PV	[...]	<25–75
	CSP with thermal storage*	[...]	90
Geothermal energy		[...]	Similar to thermal
Hydropower	Run of river	[...]	0–90
	Reservoir	[...]	Similar to thermal
Ocean energy	Tidal range	[...]	<10
	Tidal current	[...]	10–20
	Wave	[...]	16
Wind energy		[...]	5–40

If a type of generation has a low capacity credit,
the available output tends to be low during high demand periods.

IPCC 2011

Integration Options for Renewables

- **Improved weather forecast**
  → better planning of renewable electricity feed-in

- **Demand side management**
  → adjust demand to renewable electricity feed-in

- **Flexible power plants**
  → provide residual load

Important Supply Side Options

- **Grid extension**
  → large area pooling of uncorrelated fluctuations (>300km): Import / Export between countries

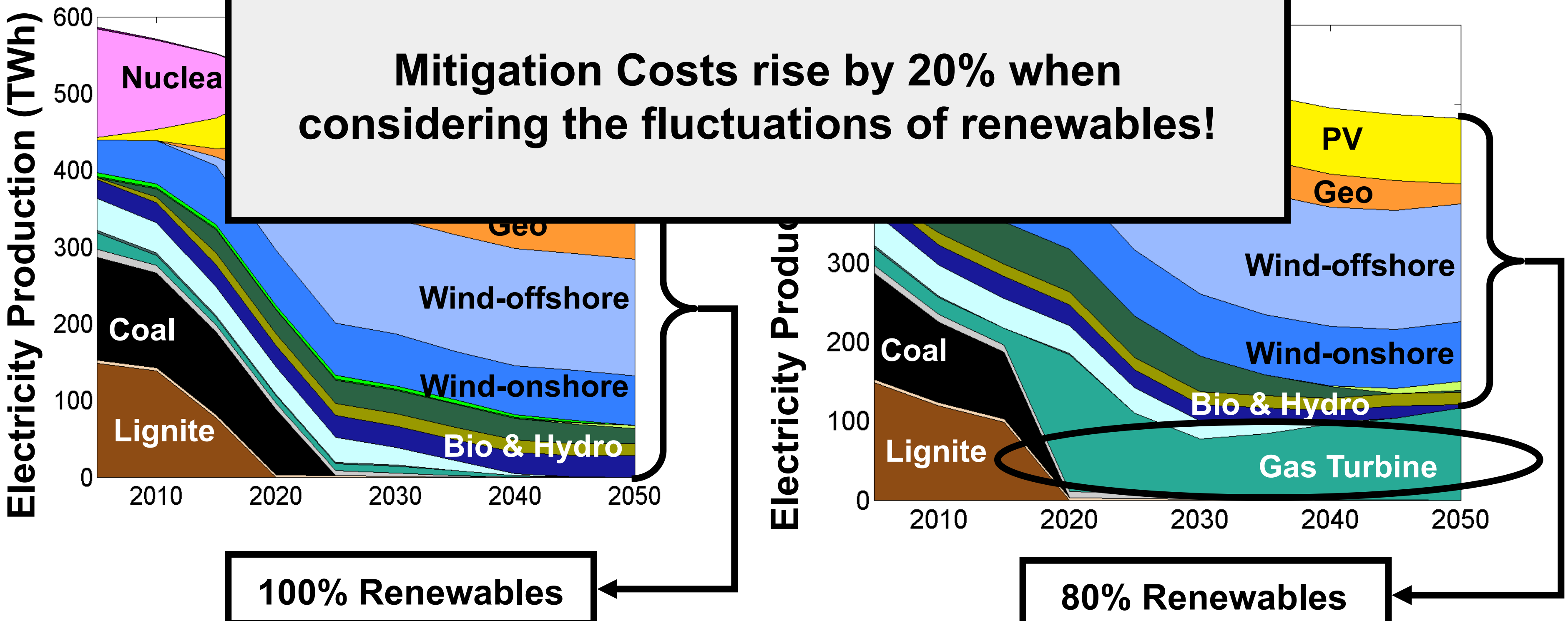
- **Energy storage**
  → remove electricity from the grid in times of high renewable generation and feed-in electricity in times of low generation

Impact of Considering Fluctuations in an Energy System Model of Germany

Most models do not take into account fluctuations explicitly:

Same scenario with consideration of fluctuations:

Mitigation Costs rise by 20% when considering the fluctuations of renewables!



Scenario: 80% domestic CO_2 emission reduction in 2050 vs. 1990

(Ueckerdt et al., 2011)

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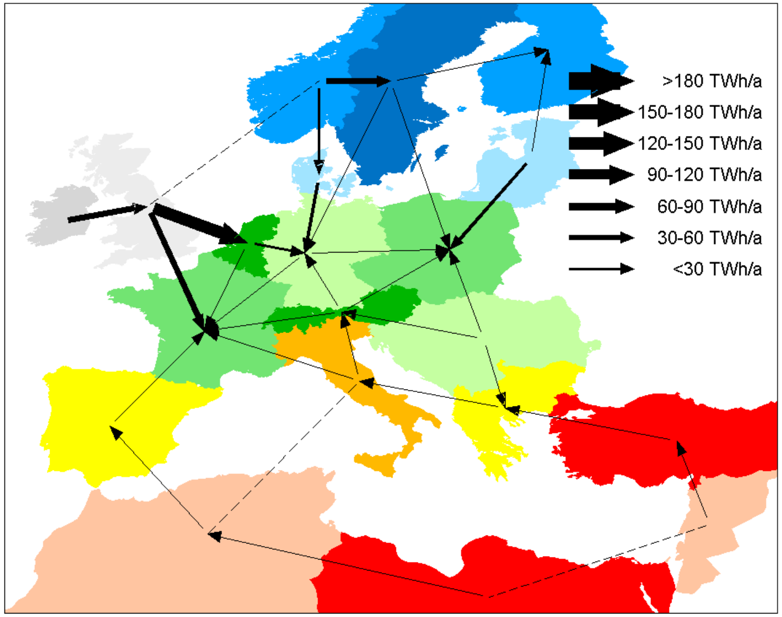
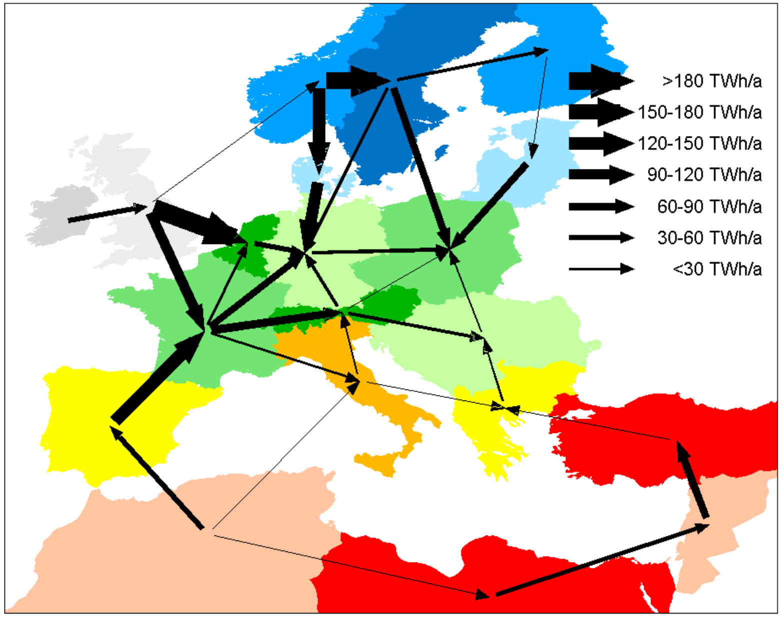
Aggregated Transmission in 2050 in an Electricity Sector model of Europe

Baseline,
no climate policy:

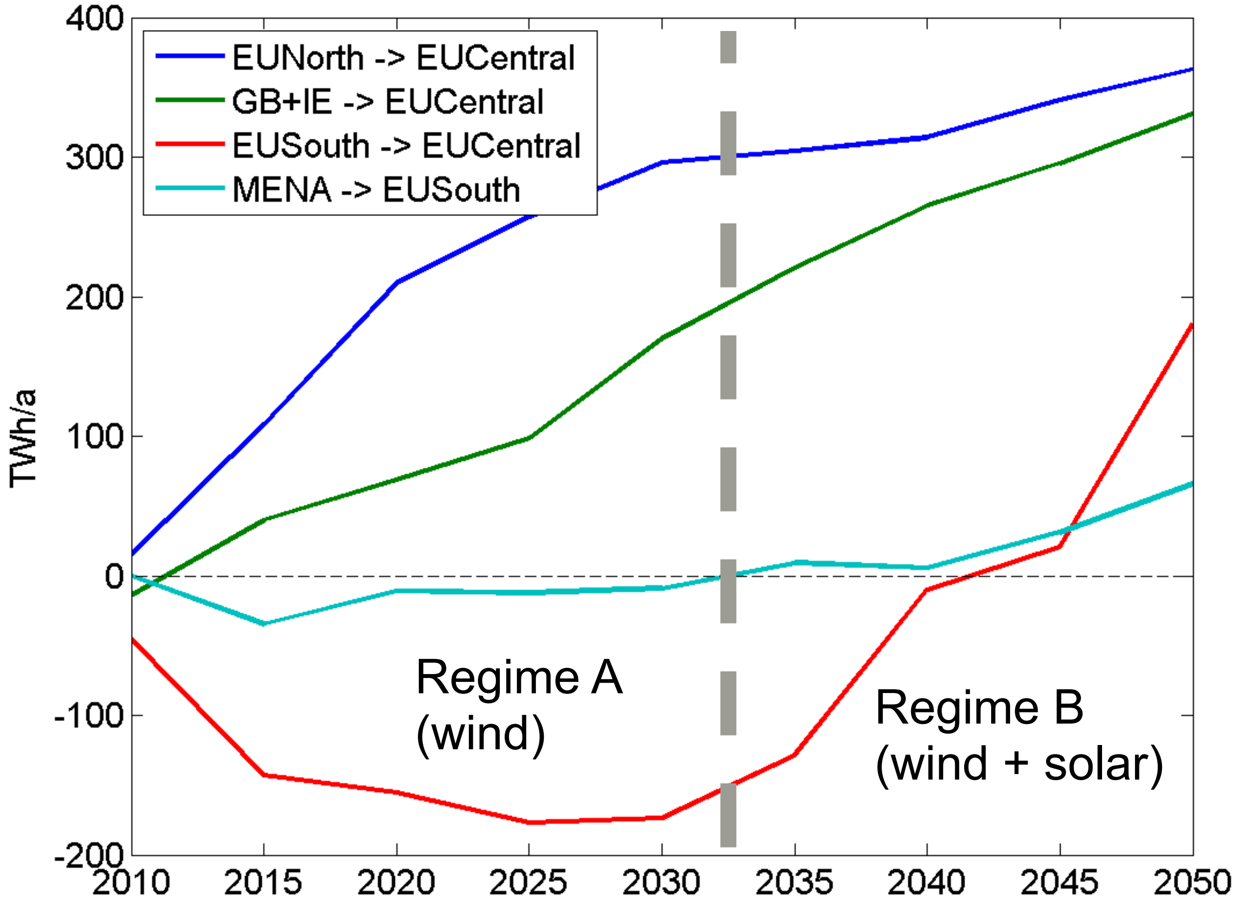


90% CO_2 reduction
in electricity sector:



Haller et al., 2012

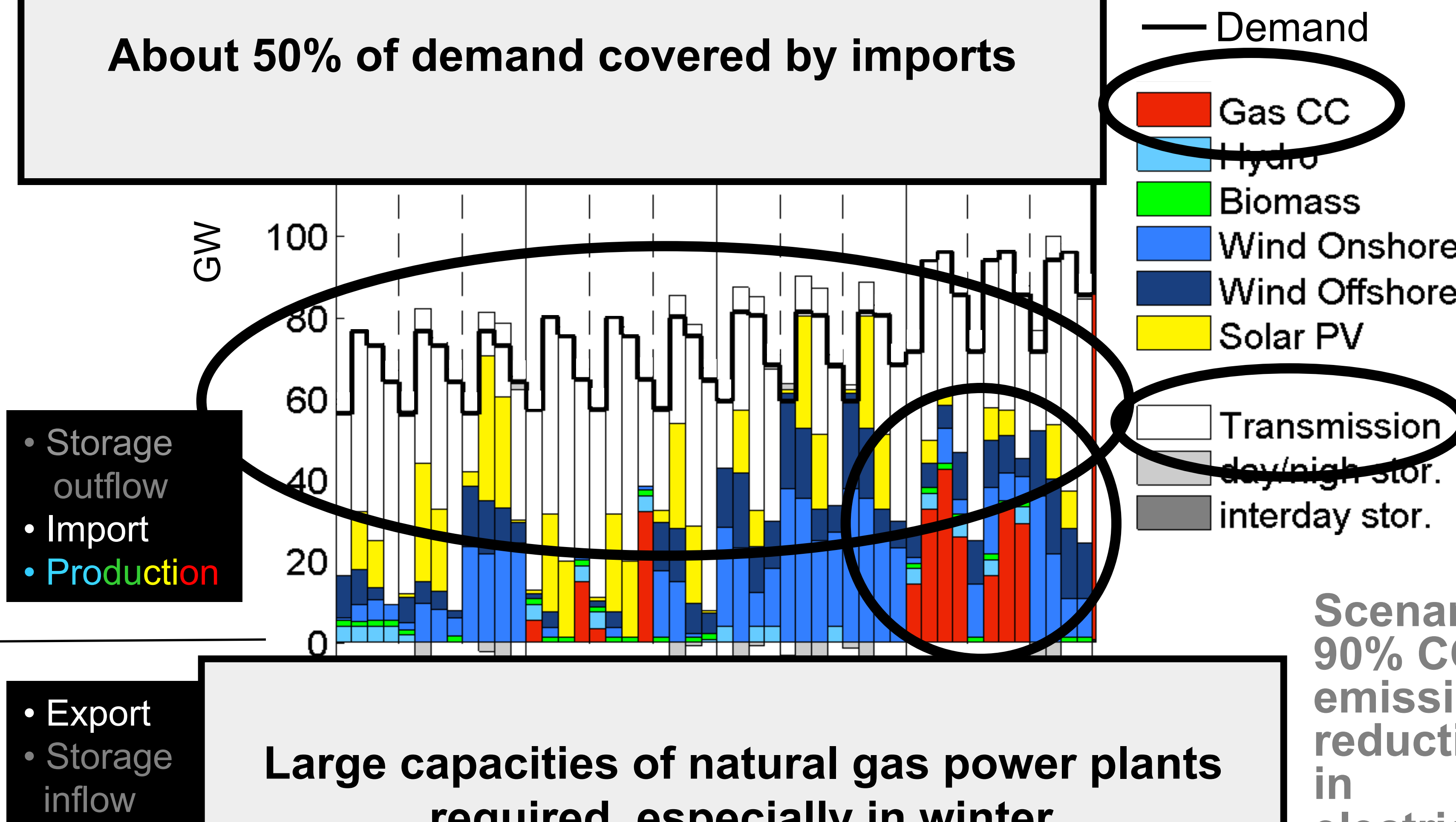
Deployment pathways are not linear



Haller et al., 2012

Germany 2050: Electricity production with network expansion (European Interconnectors)

About 50% of demand covered by imports



Large capacities of natural gas power plants required, especially in winter

Scenario: 90% CO_2 emission reduction in electricity sector

Haller et al., 2012

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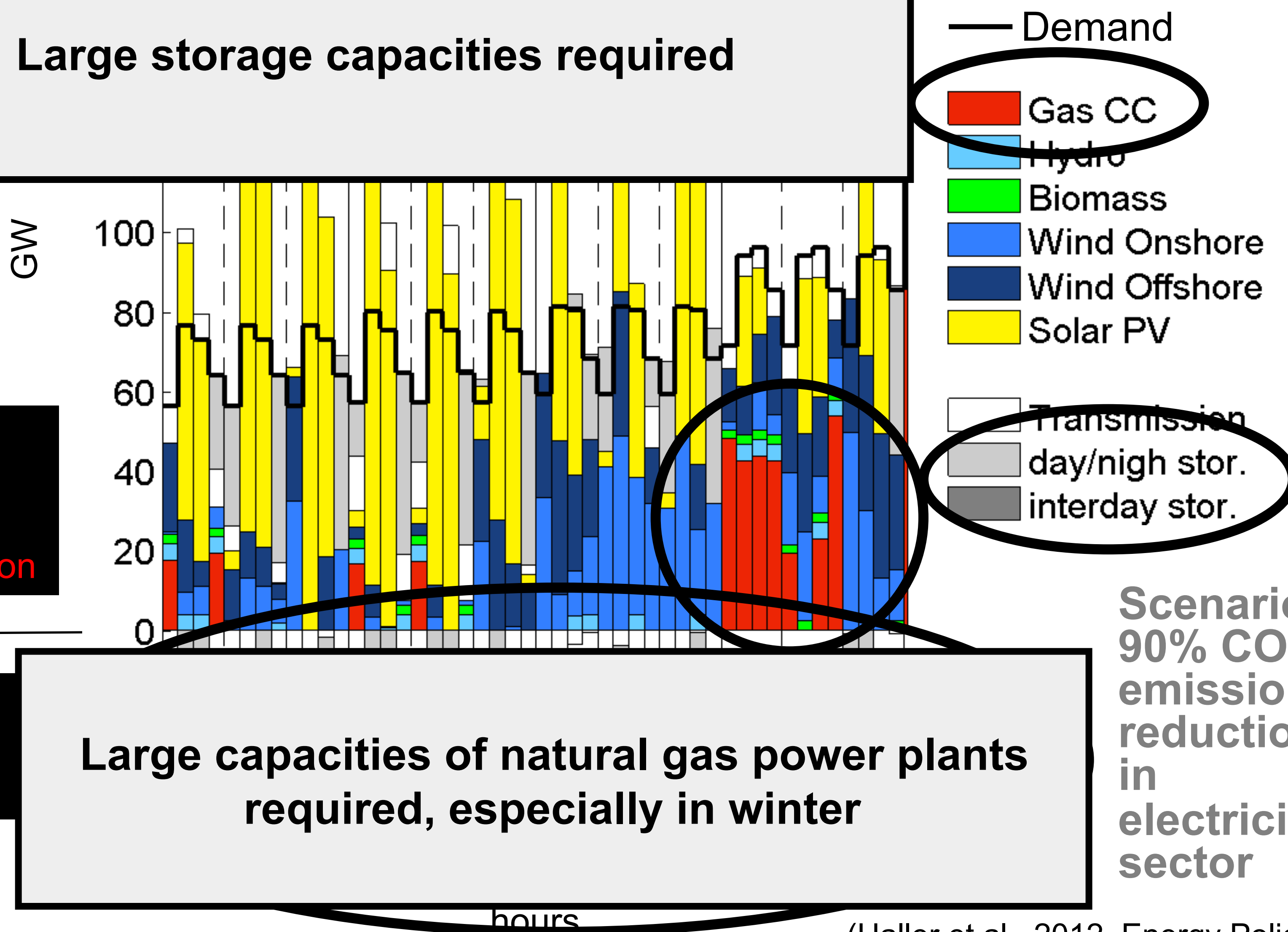
Germany 2050: Electricity production without network expansion (Autarkic Germany)

Large storage capacities required



- Storage outflow
- Import
- Production

- Export
- Storage inflow

Large capacities of natural gas power plants required, especially in winter

Scenario: 90% CO_2 emission reduction in electricity sector

(Haller et al., 2012, Energy Policy)

Interim Synthesis

Large back-up capacities of flexible gas power plants are required to provide residual load in extended times of low renewable electricity generation (European winter)…

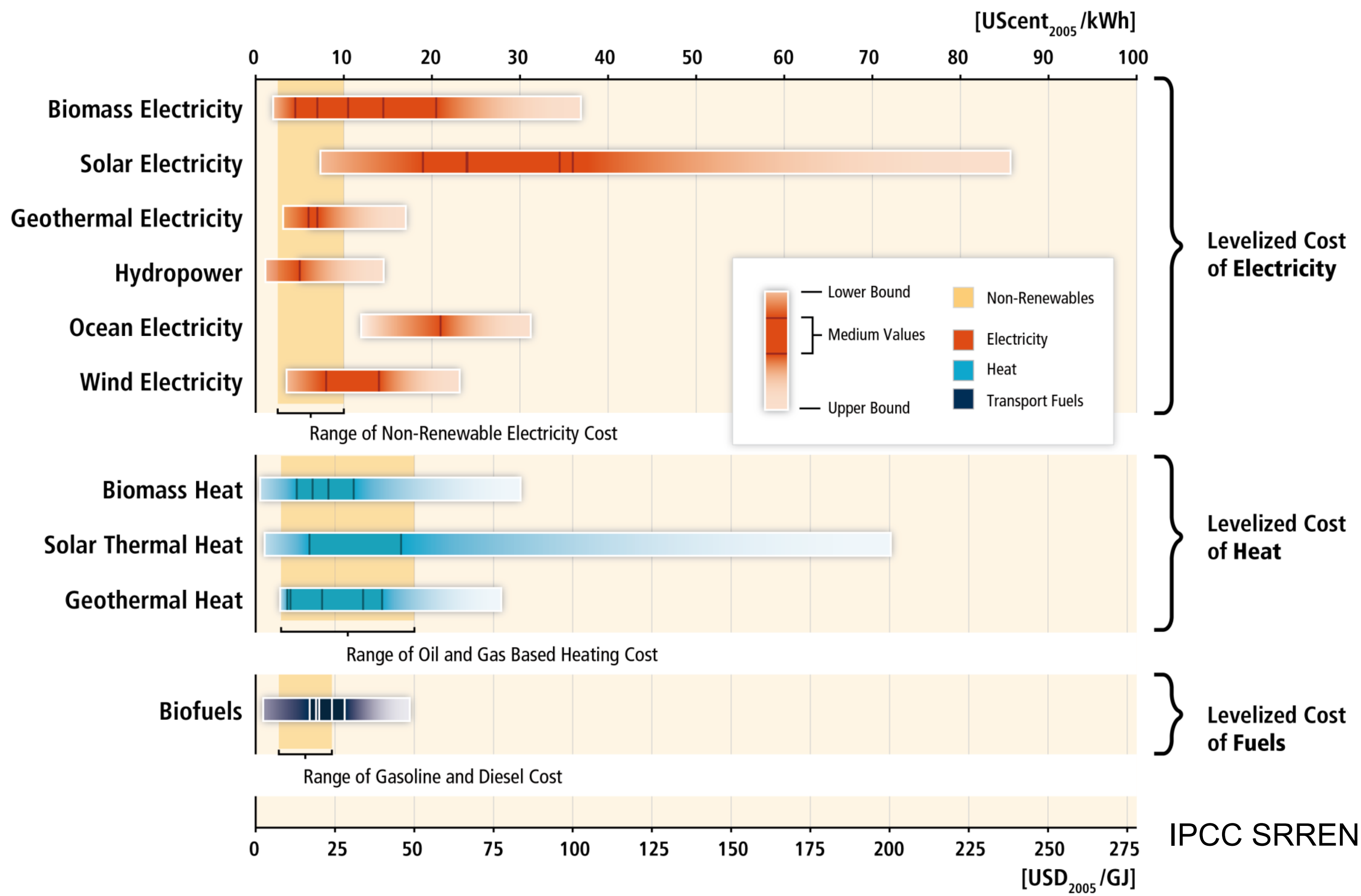
…even with a European integrated electricity grid

…even with large day/night or medium-term storage capacities (e.g. pumped hydro)

What are the implications for the costs of renewables?

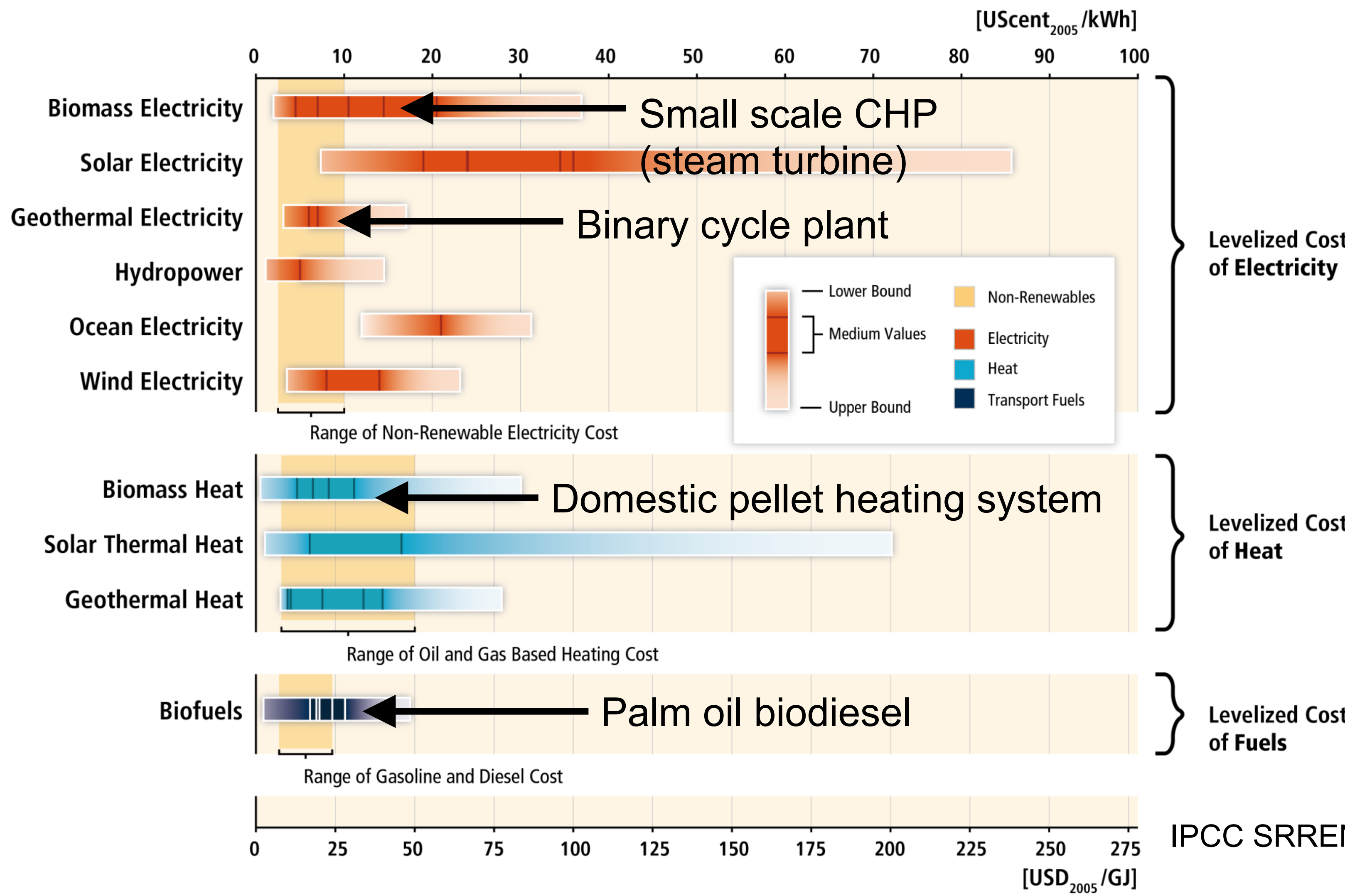
5. SYSTEM INTEGRATION FROM A COST PERSPECTIVE

The Costs of Renewables are often still higher than those of Non-Renewables but…



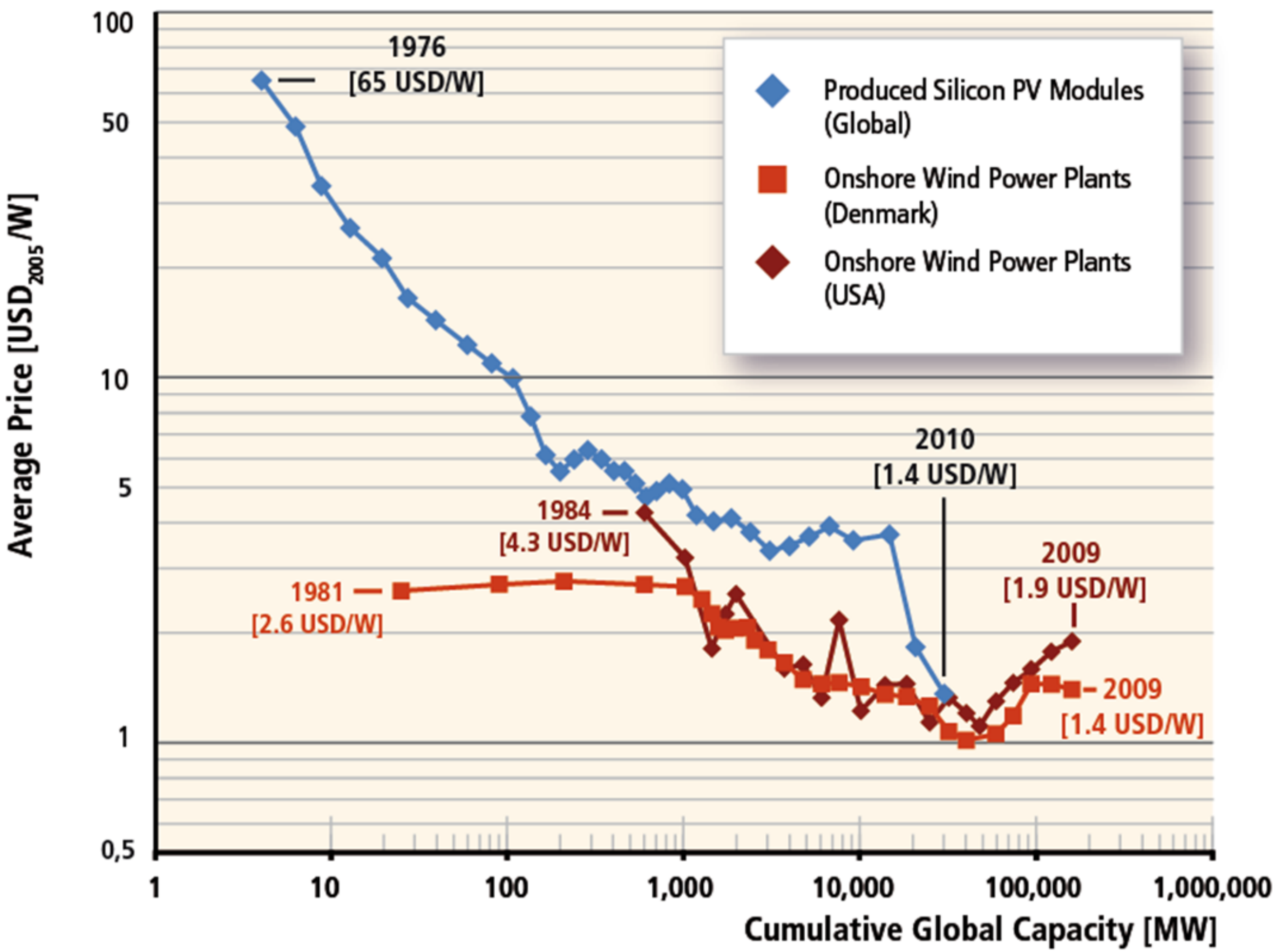
IPCC SRREN (2011)

...some RE Technologies are already competitive

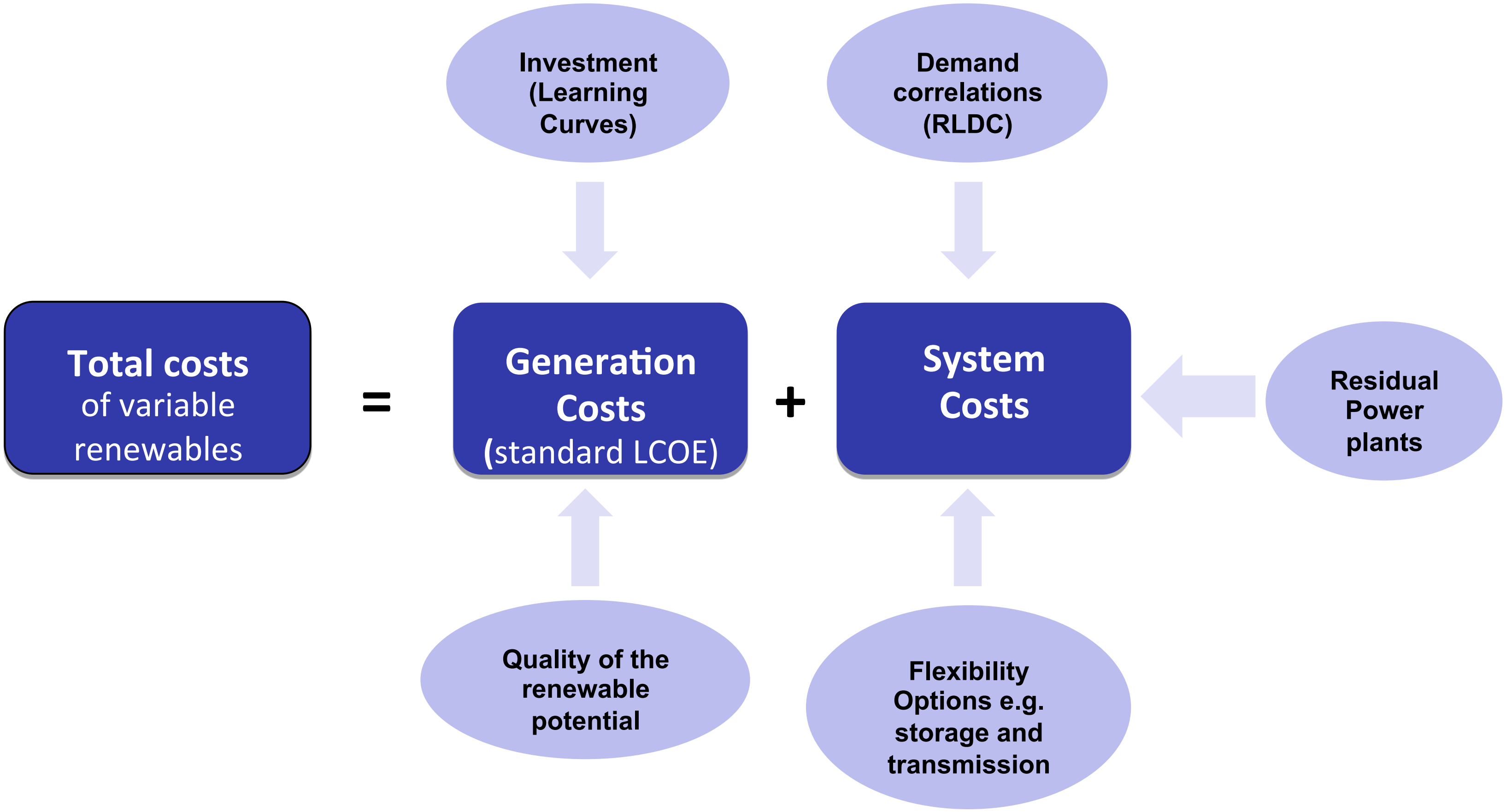


IPCC SRREN (2011)

Learning-by-Doing



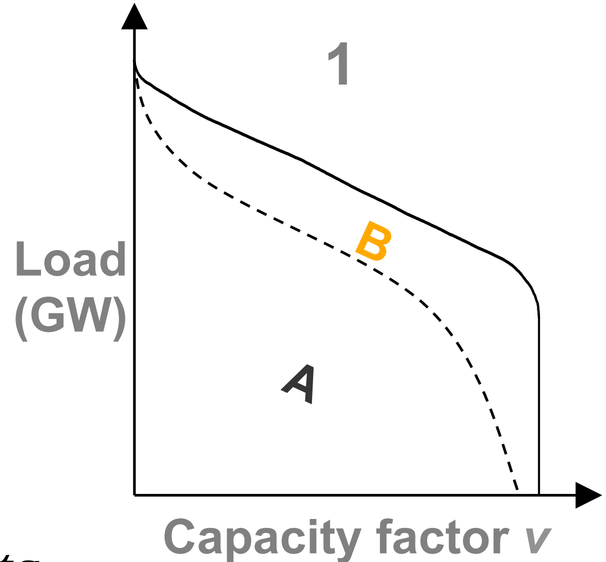
What are the total costs of variable renewables (VRE)?

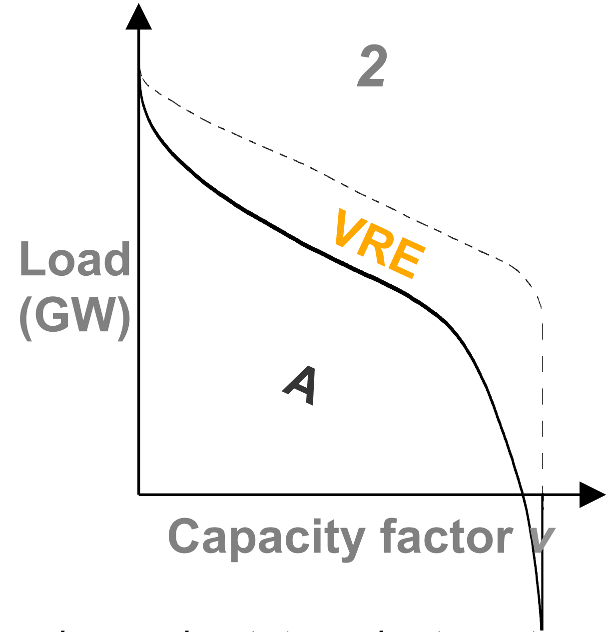


Additional system costs can be crucial.
LCOE indicator needs to be extended.

„System LCOE“ cover the arguments of Joskow and Hirth from a cost perspective

	Private perspective	**System perspective**
Cost	Standard LCOE	System LCOE
Value/ Benefit	VRE investor’s profits depend on price distribution (Joskow‘s 2011)	Market value of VRE decreases with increasing shares (Hirth 2012)





Total costs:

$C_1 = C_1(A) + C_1(B)$

$C_2 = C_2(A) + C_2(VRE)$

Cost difference: $C_2 - C_1 = \underbrace{C_2(A) - C_1(A)}_{\Delta} \underbrace{- C_1(B)}_{Value} + \underbrace{C_2(VRE)}_{Cost}$

$C_1(A) < C_2(A)$

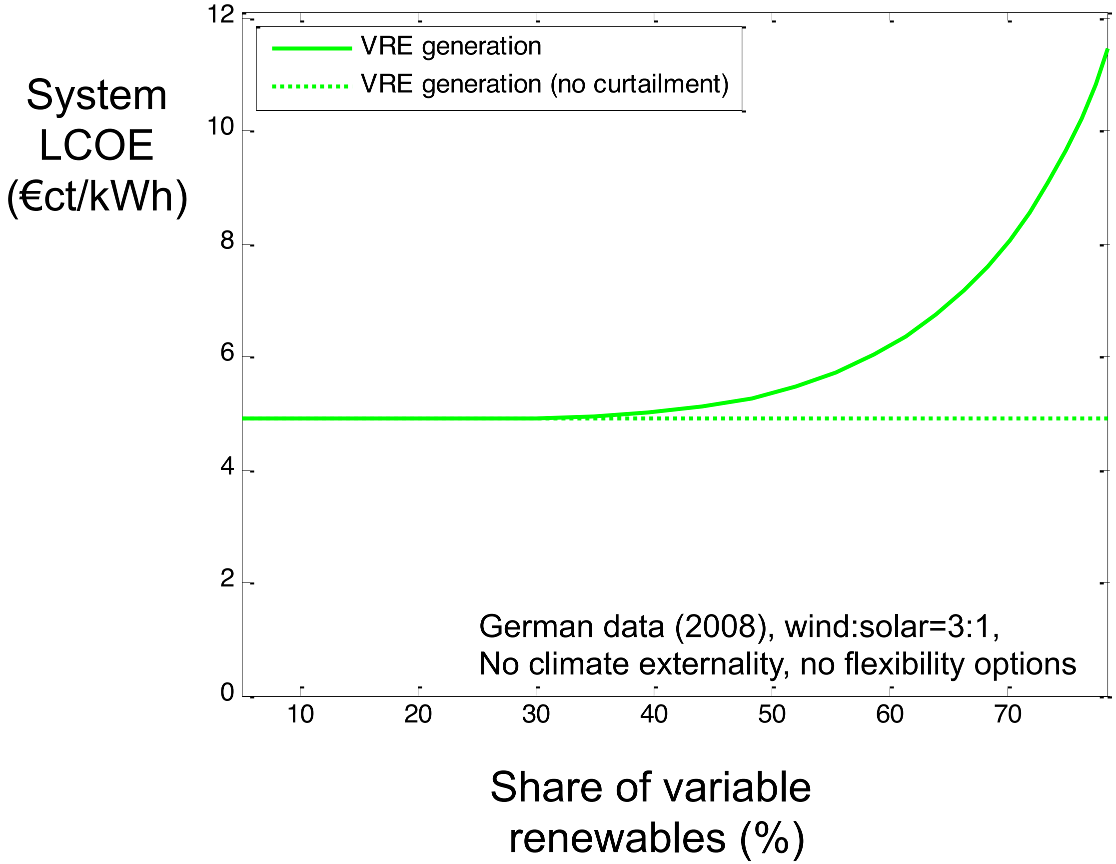
System costs of VRE: $\Delta = C_2(A) - C_1(A)$ $\rightarrow \Delta / VRE$

Cost perspective: $LCOE_{VR}$ / VRE

Value perspective: $(B)/VRE$ $(A)/V$

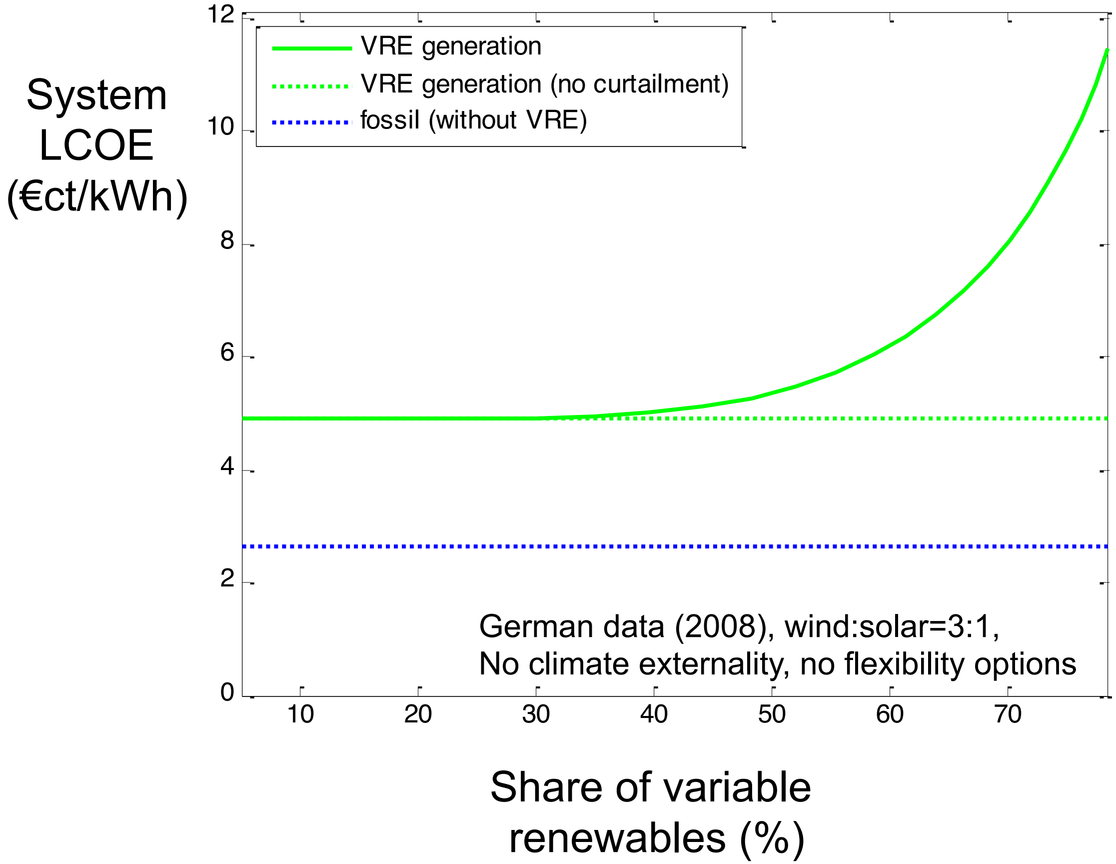
$p_2(A) G_A / VRE$

System LCOE increase with higher share of variable renewables



- huge challenge with high shares: VRE LCOE increase due to curtailment

System LCOE increase with higher share of variable renewables



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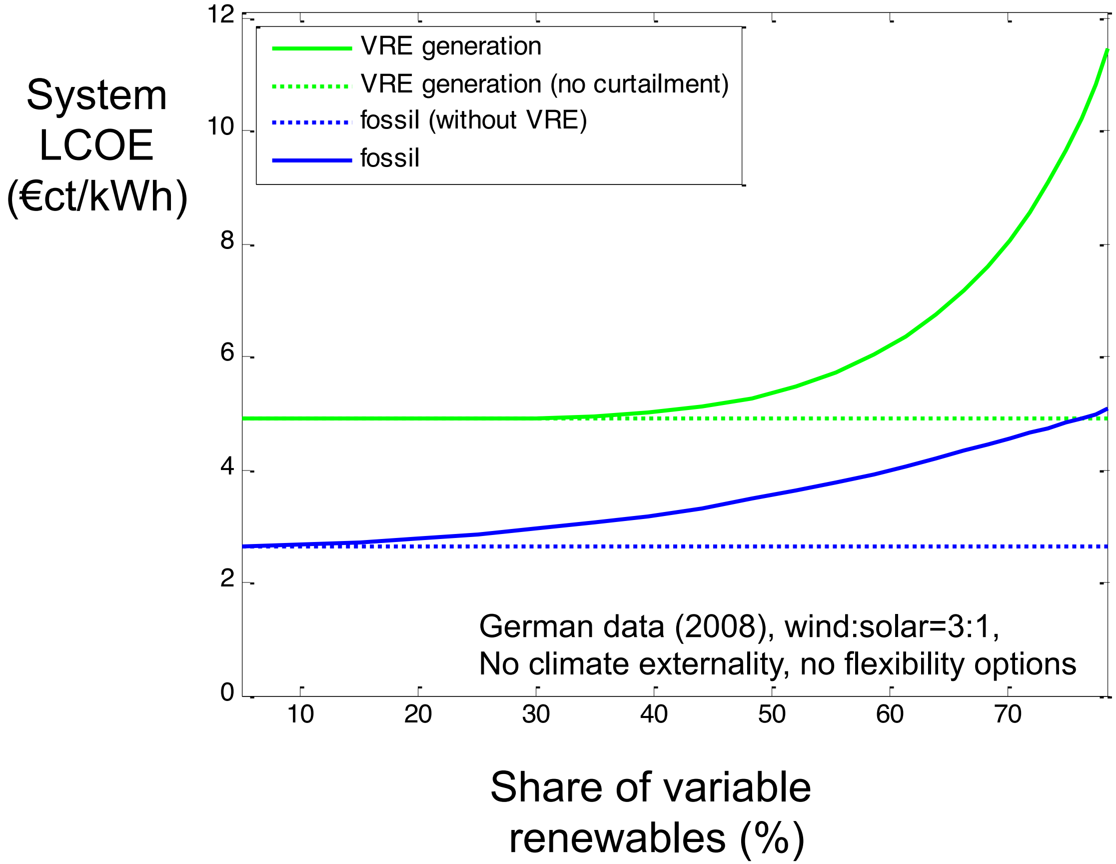

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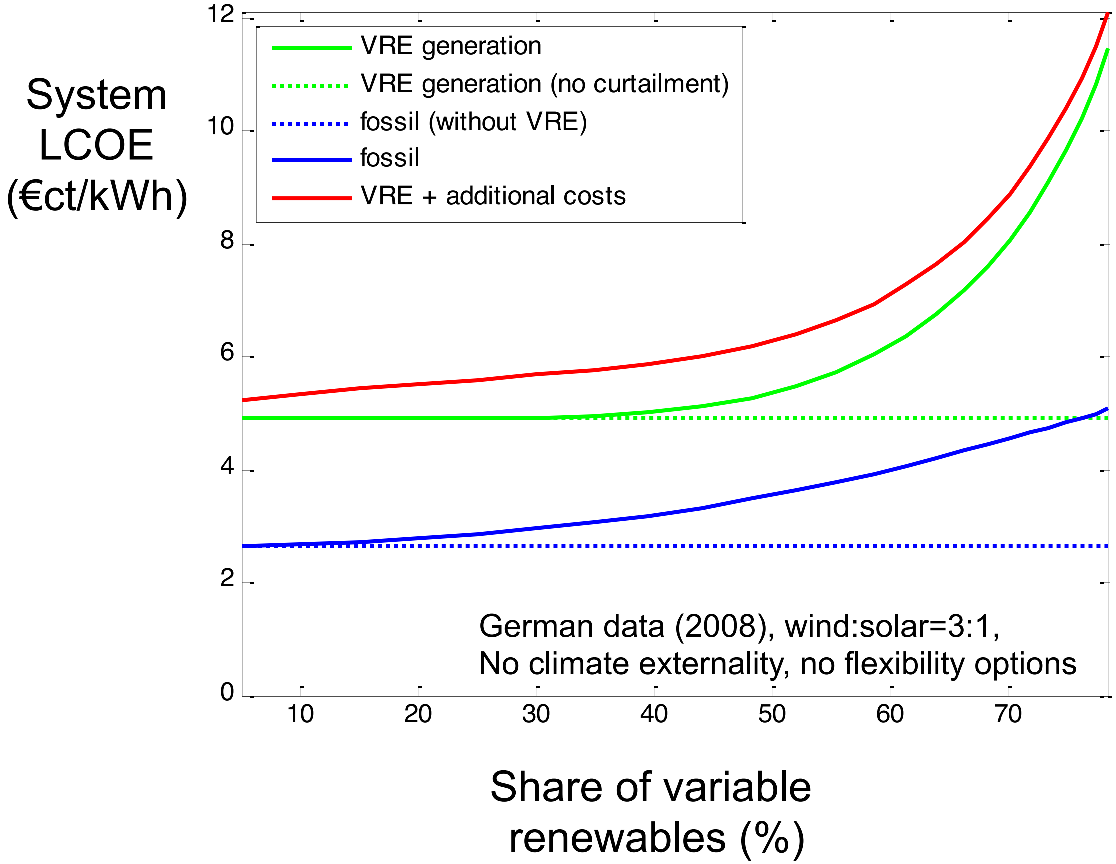
- fossil system LCOE increase with VRE

System LCOE increase with higher share of variable renewables



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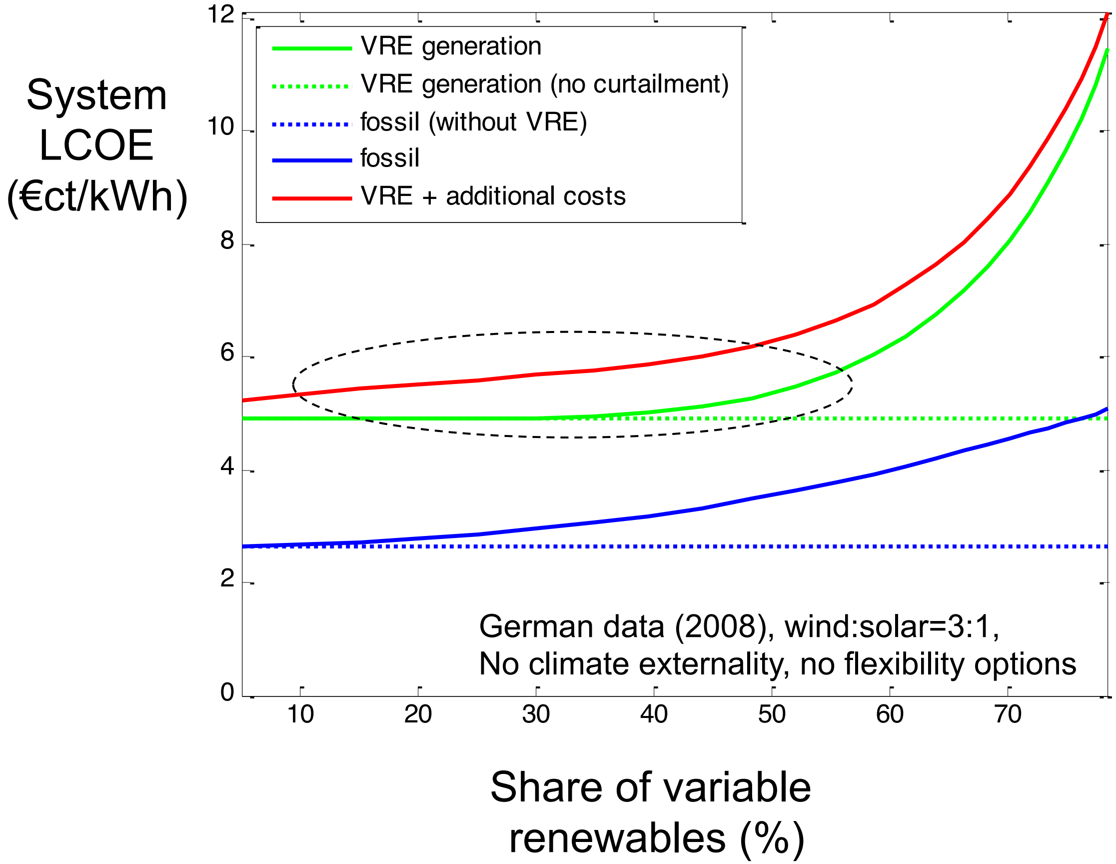

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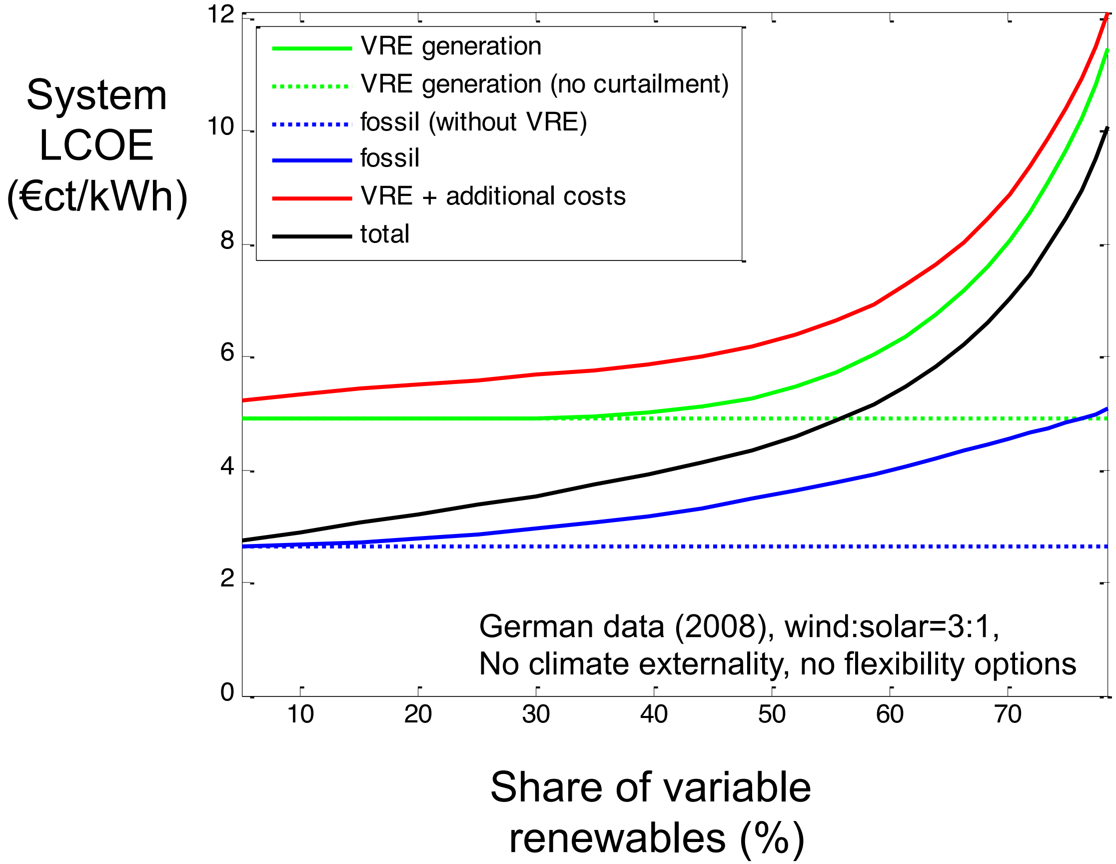

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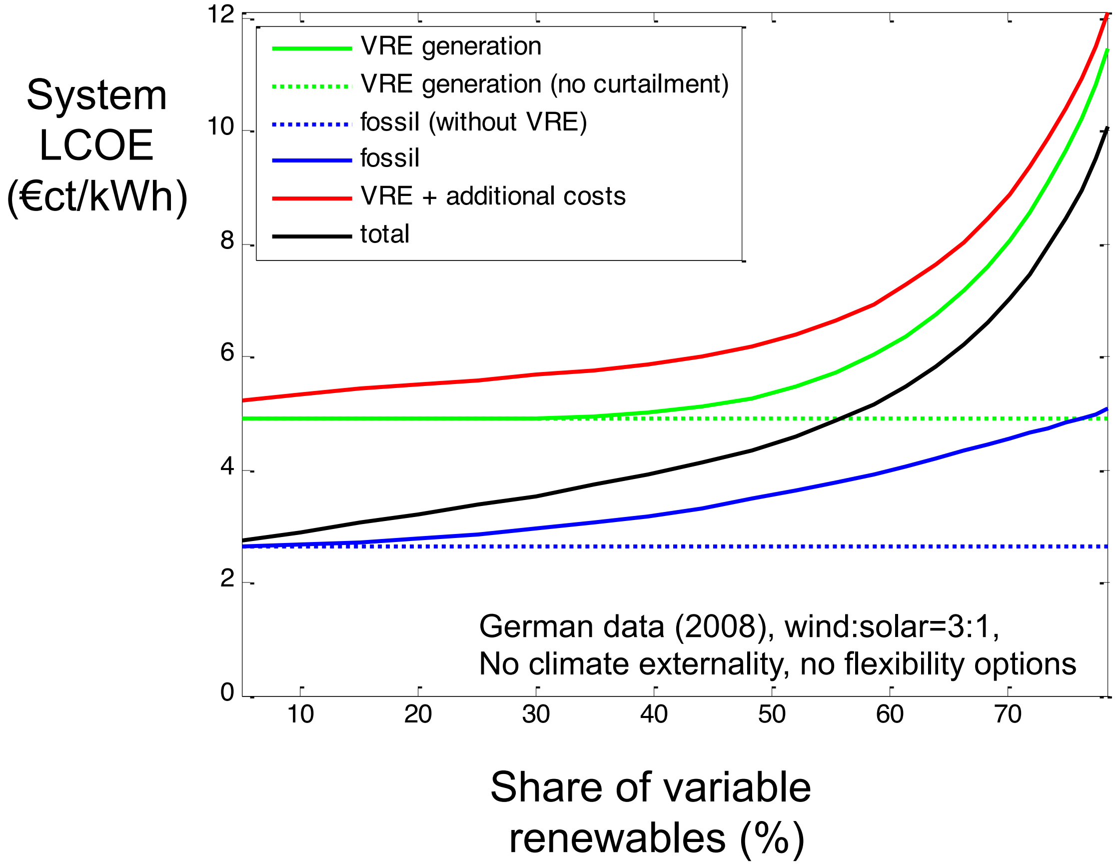

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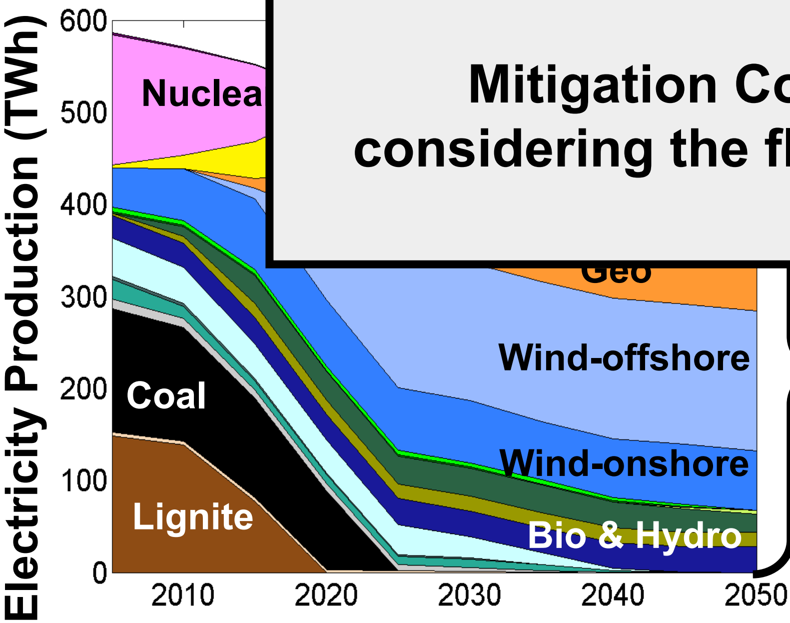
- system implication fully considered
- social cost perspective → indicator for policy maker
- method not very simple → improve framework

Impact of Considering Fluctuations in an Energy System Model of Germany

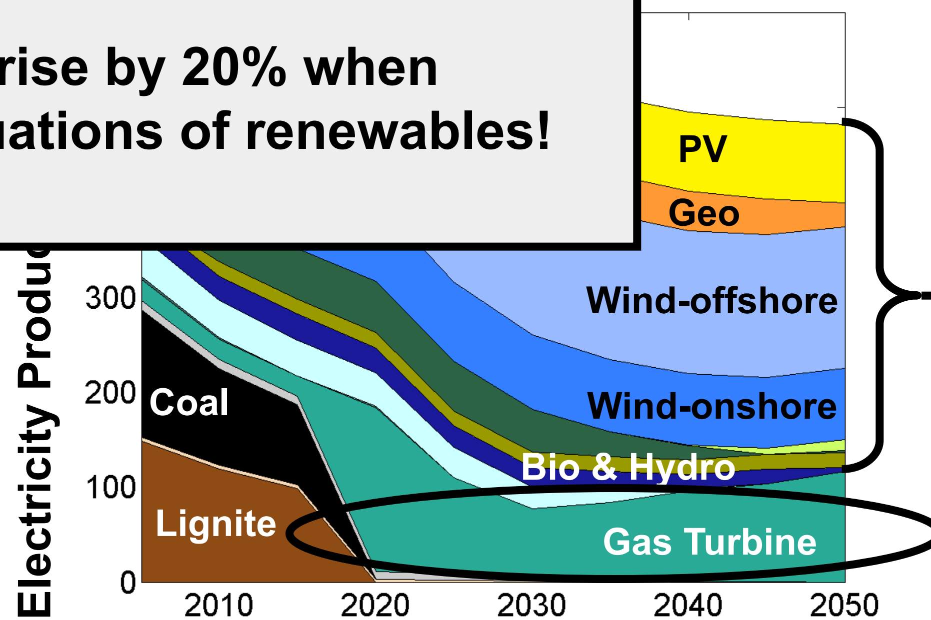
Most models do not take into account fluctuations explicitly:



100% Renewables

Mitigation Costs rise by 20% when considering the fluctuations of renewables!

Same scenario with consideration of fluctuations:



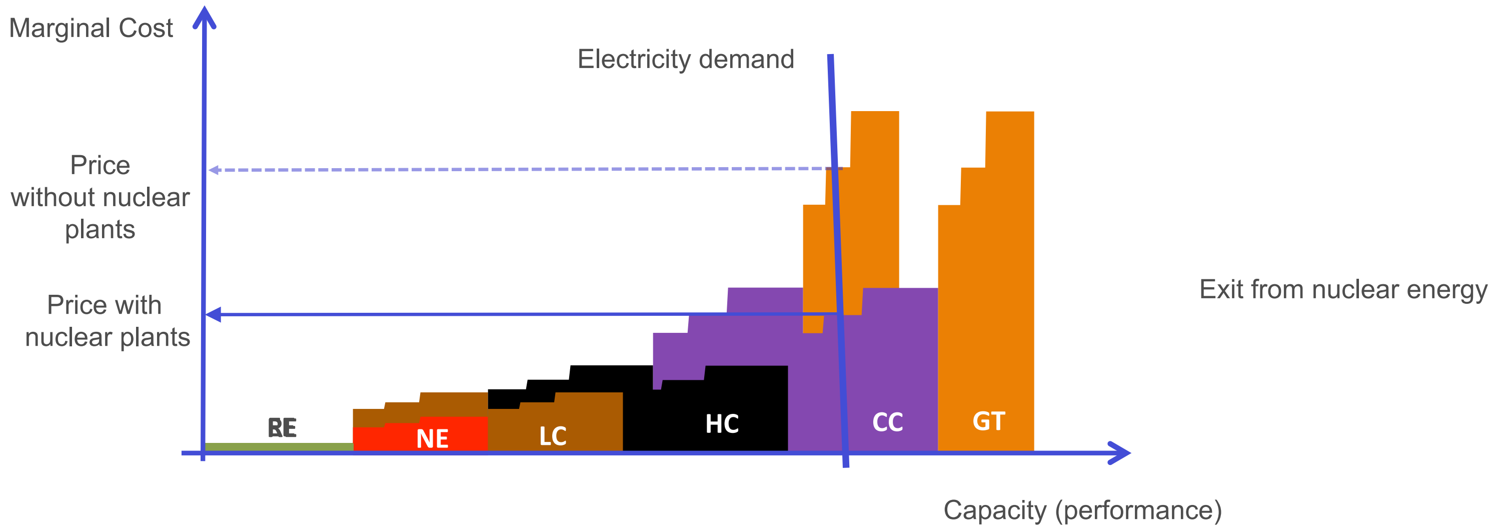
80% Renewables

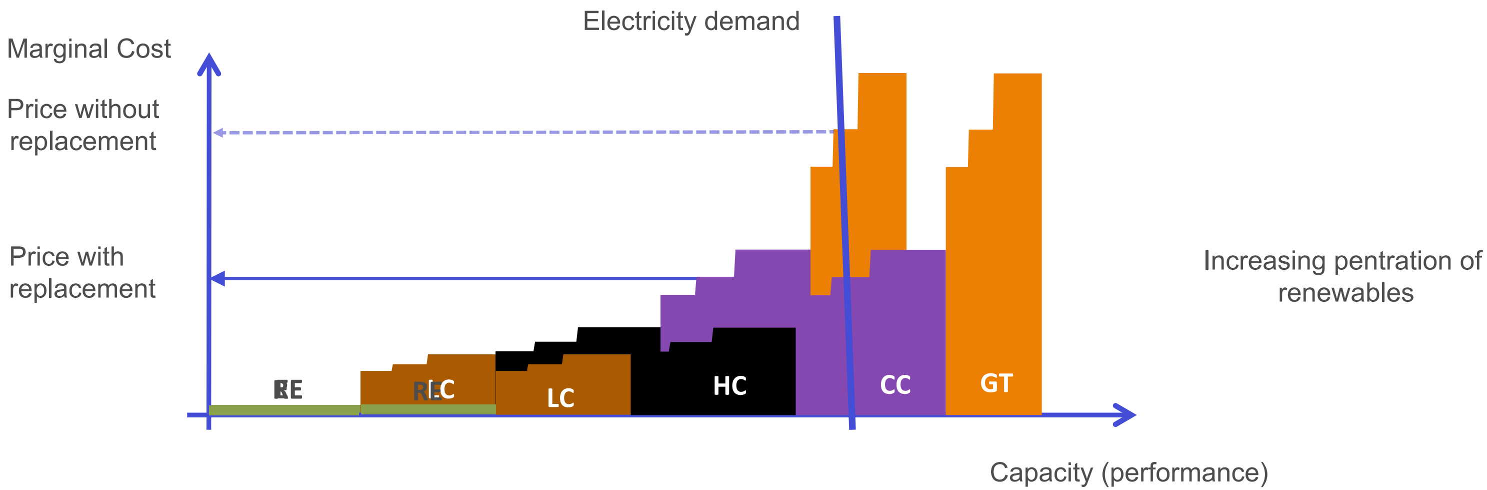
Scenario: 80% domestic CO_2 emission reduction in 2050 vs. 1990

(Ueckerdt et al., 2011)

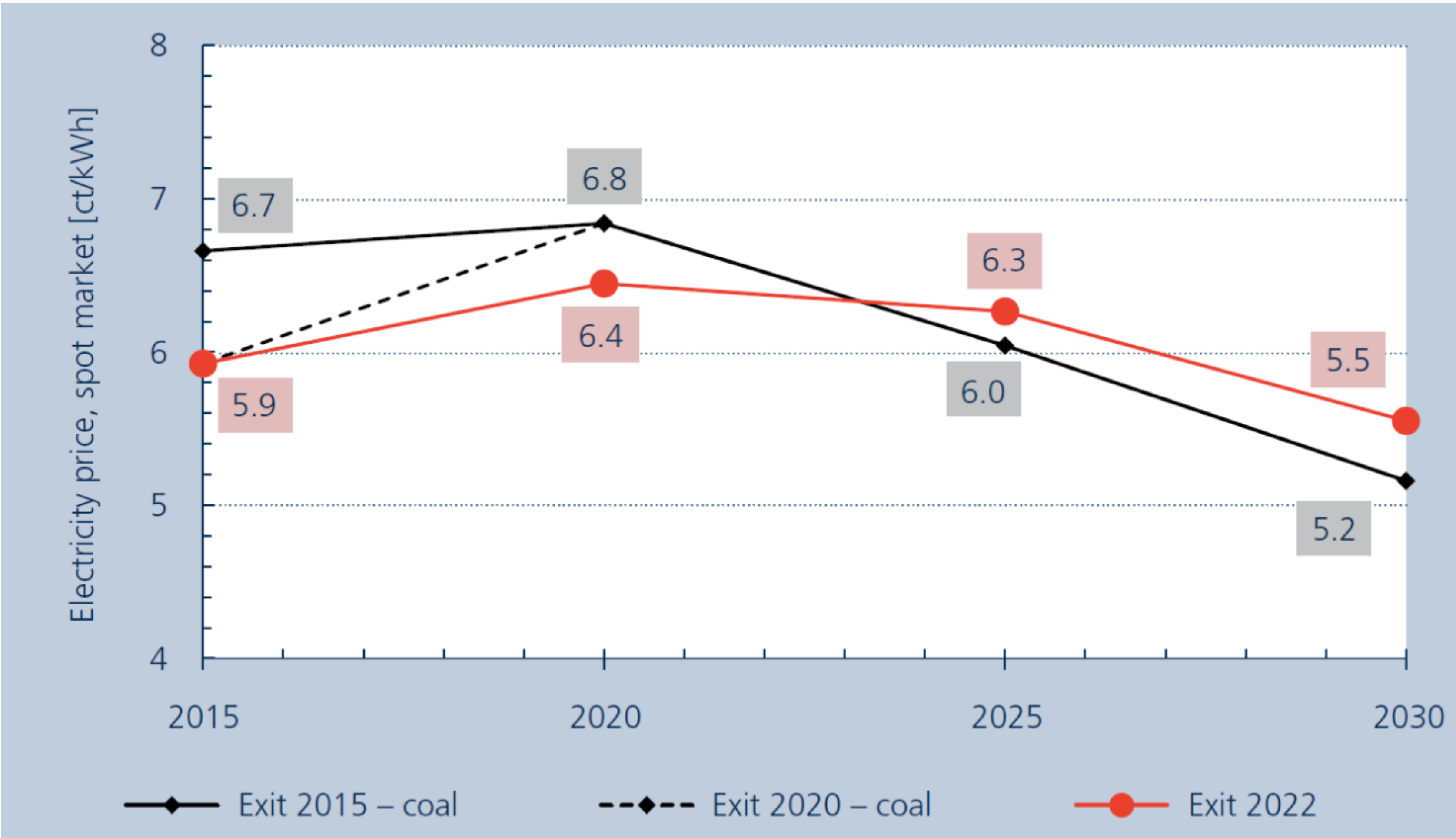
6. SYSTEM INTEGRATION FROM A MARKET PERSPECTIVE

The Current Market System: Merit Order Pricing





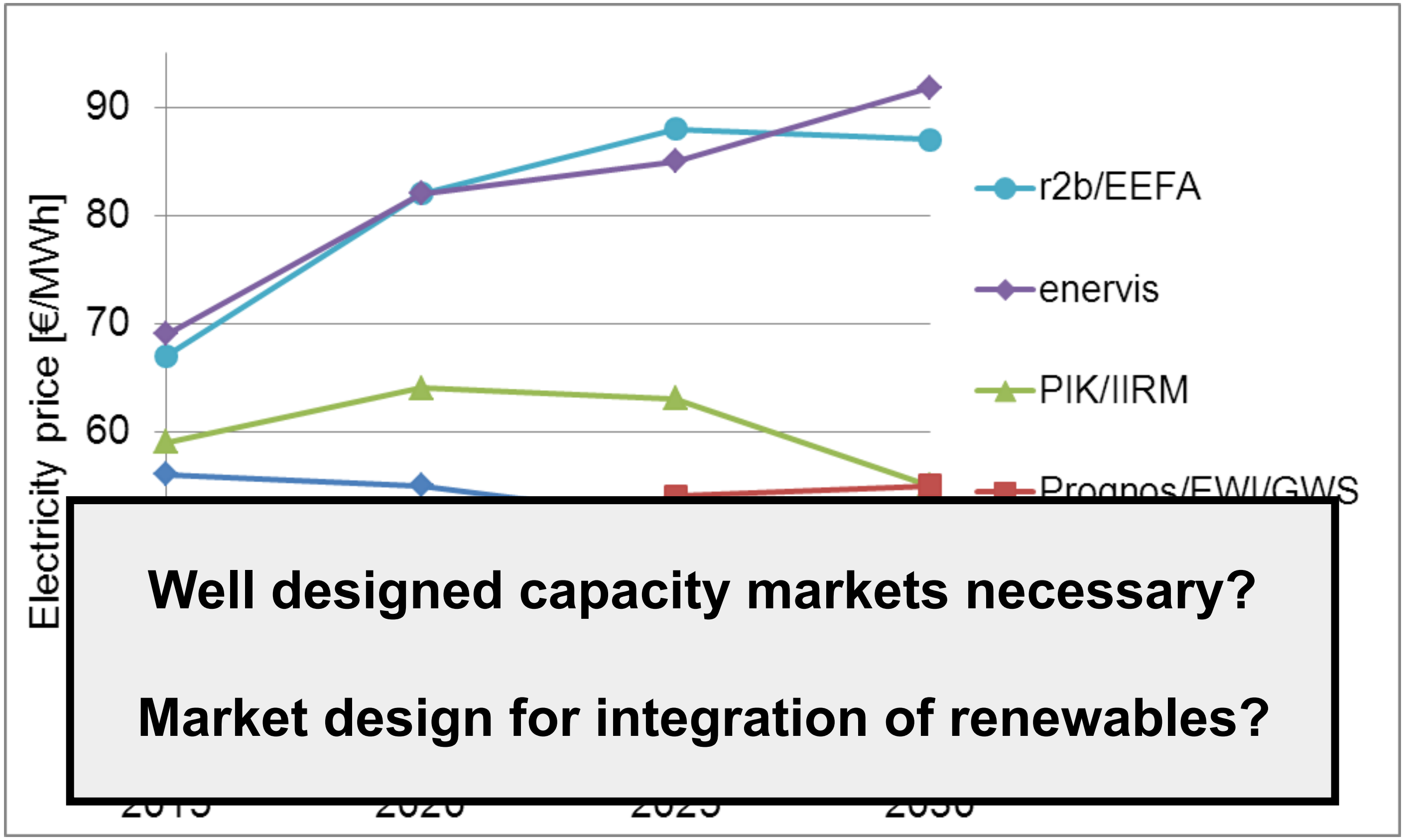
Wholesale Market Prices



Merit-Order effect of increasing shares of renewables:
Decreasing power prices

(Knopf et al. , 2011)

Wholesale Market Prices



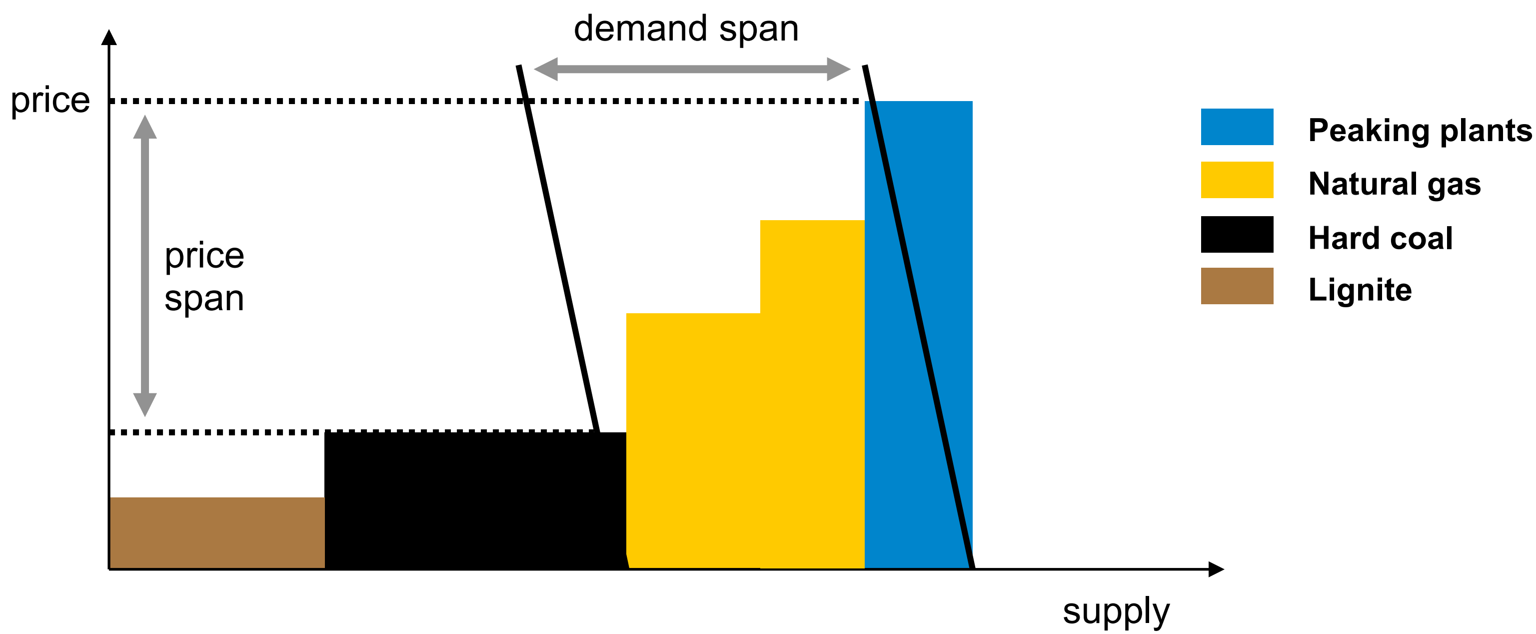
Well designed capacity markets necessary?

Market design for integration of renewables?

Knopf, Pahle, Edenhofer (2012)

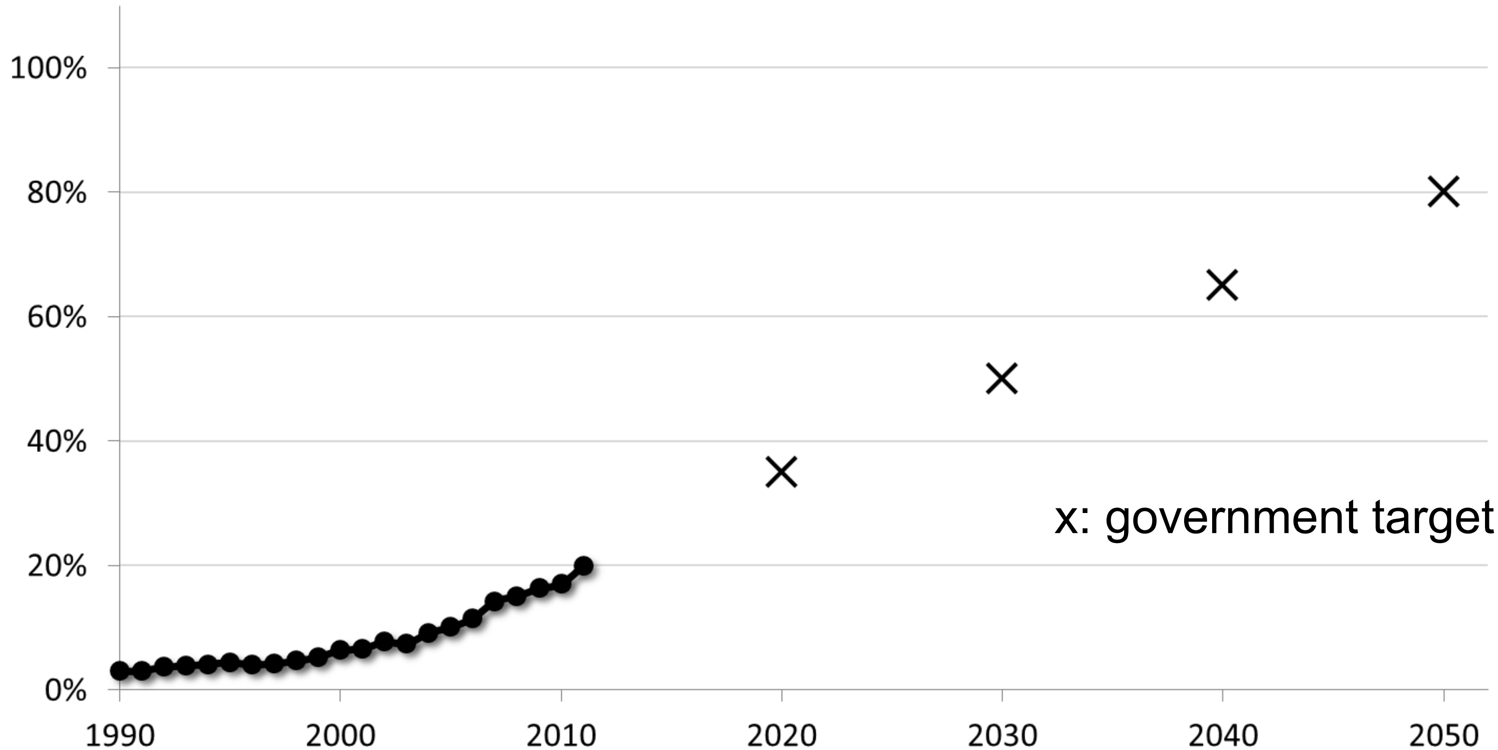
- Uncertainty due to further development of exogenous drivers, e.g. gas price
- Uncertainty due to market design for renewables

System Integration

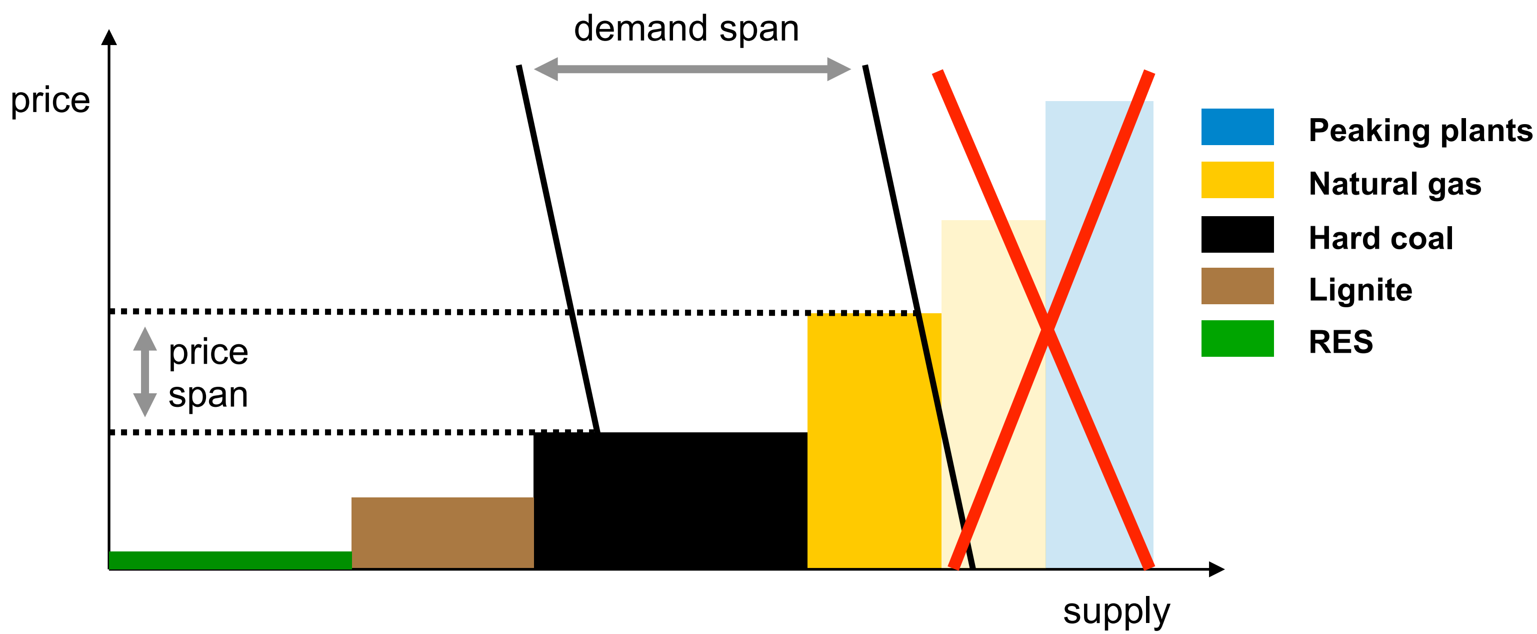


- Demand: Fluctuating, Supply: Conventional only
- Price set by marginal plant, mostly natural gas
- Avg. price close to marginal cost of natural gas plants
- High price span due to supply curve curvature

The Energy Tranformation in Germany: Increasing Share of Renewable Energy in Electricity Generation



System Integration



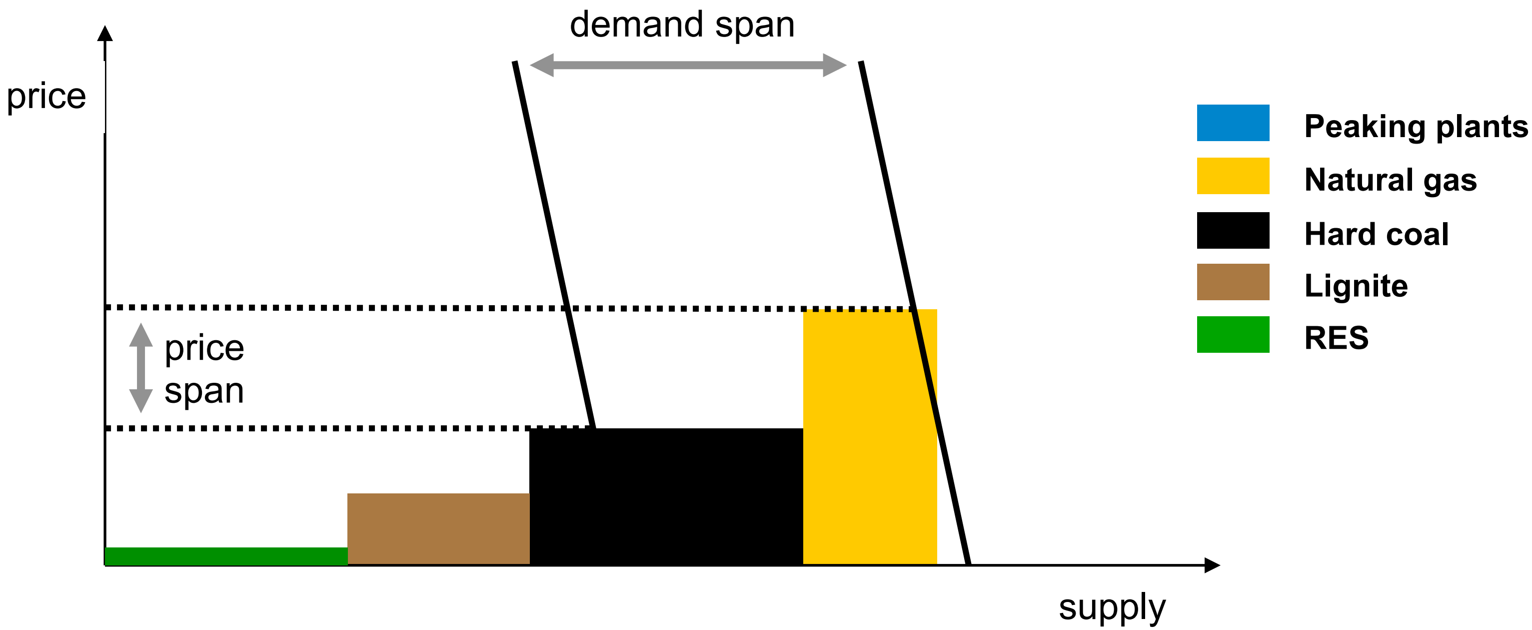
- **RES** entering the market at zero marginal costs

→ Peaking plants and less efficient natural gas no longer needed: Plants **decommissioned**

→ Low **average price** reduces invest. incentive for **plants**

→ Low **price span** reduces invest. incentive for **storage**

System Integration



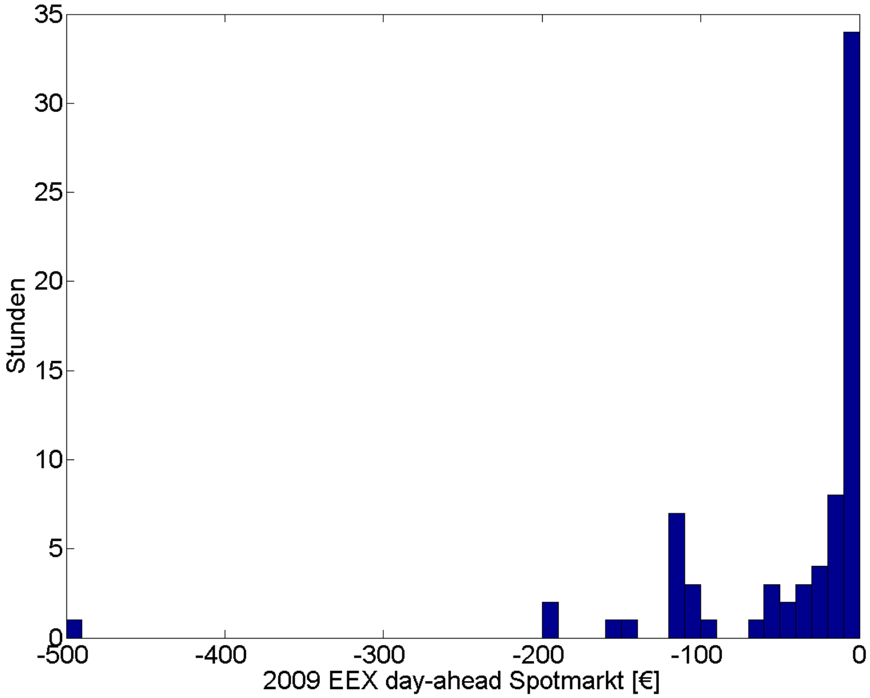
- But: **Fluctuations** matter if share of RES is high!

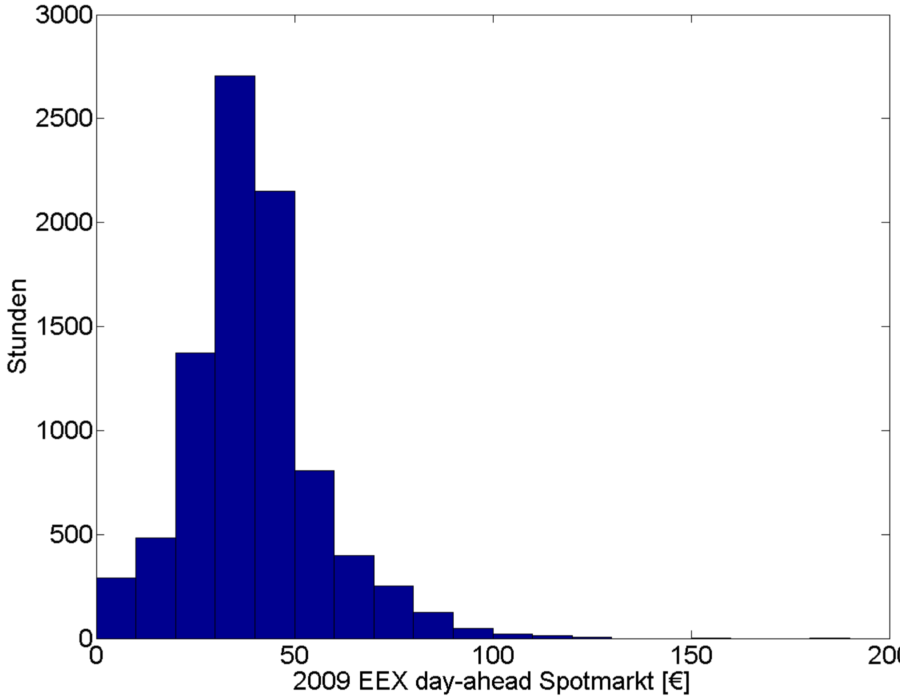
→ **"Left shift"** of convent. supply if RES supply is low

→ Insufficient supply if demand is high at the same time

→ **Reliability/security of supply** endangered

Negative Spot Prices: Indicator for a Market Failure





System Integration

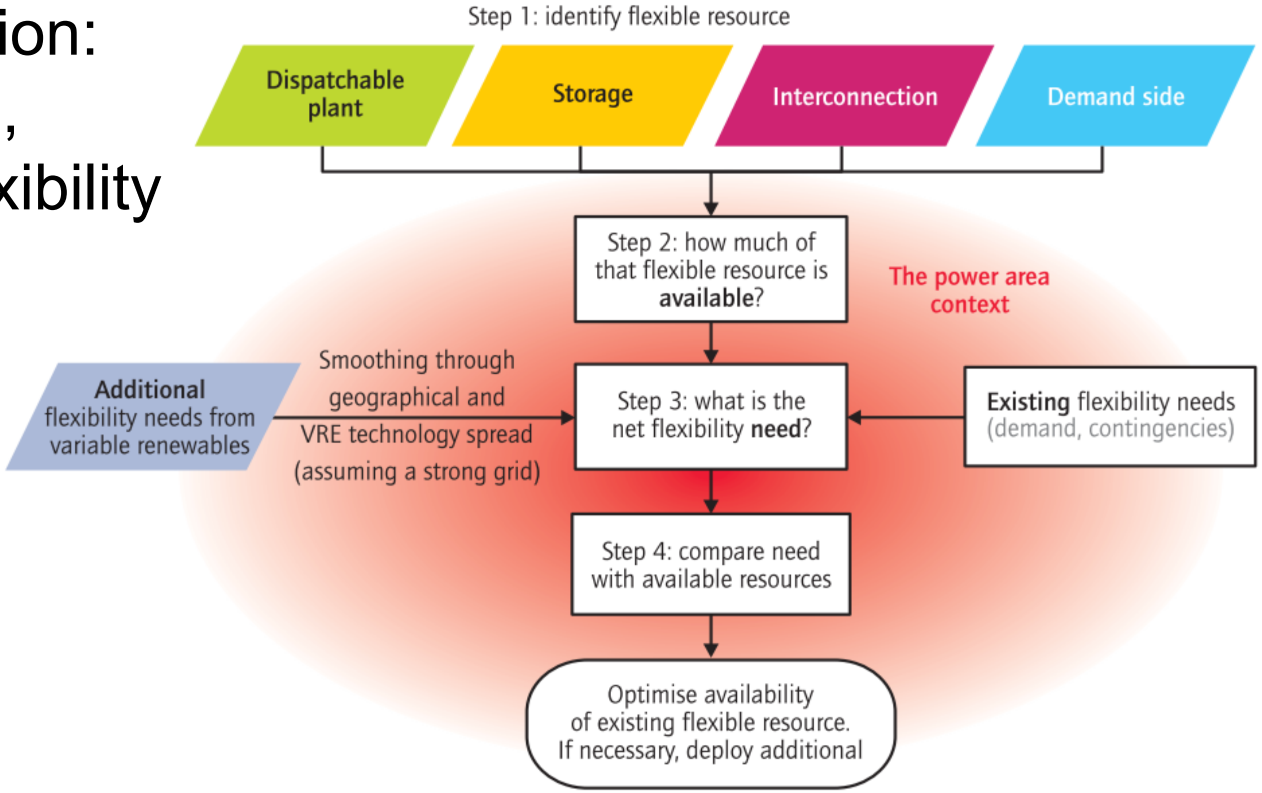
- Challenge **long-term** scale: Delivering **adequate capacity**

→ Possible solution: **Capacity mechanism**

- Challenge **short-term** scale: Delivering **flexibility**

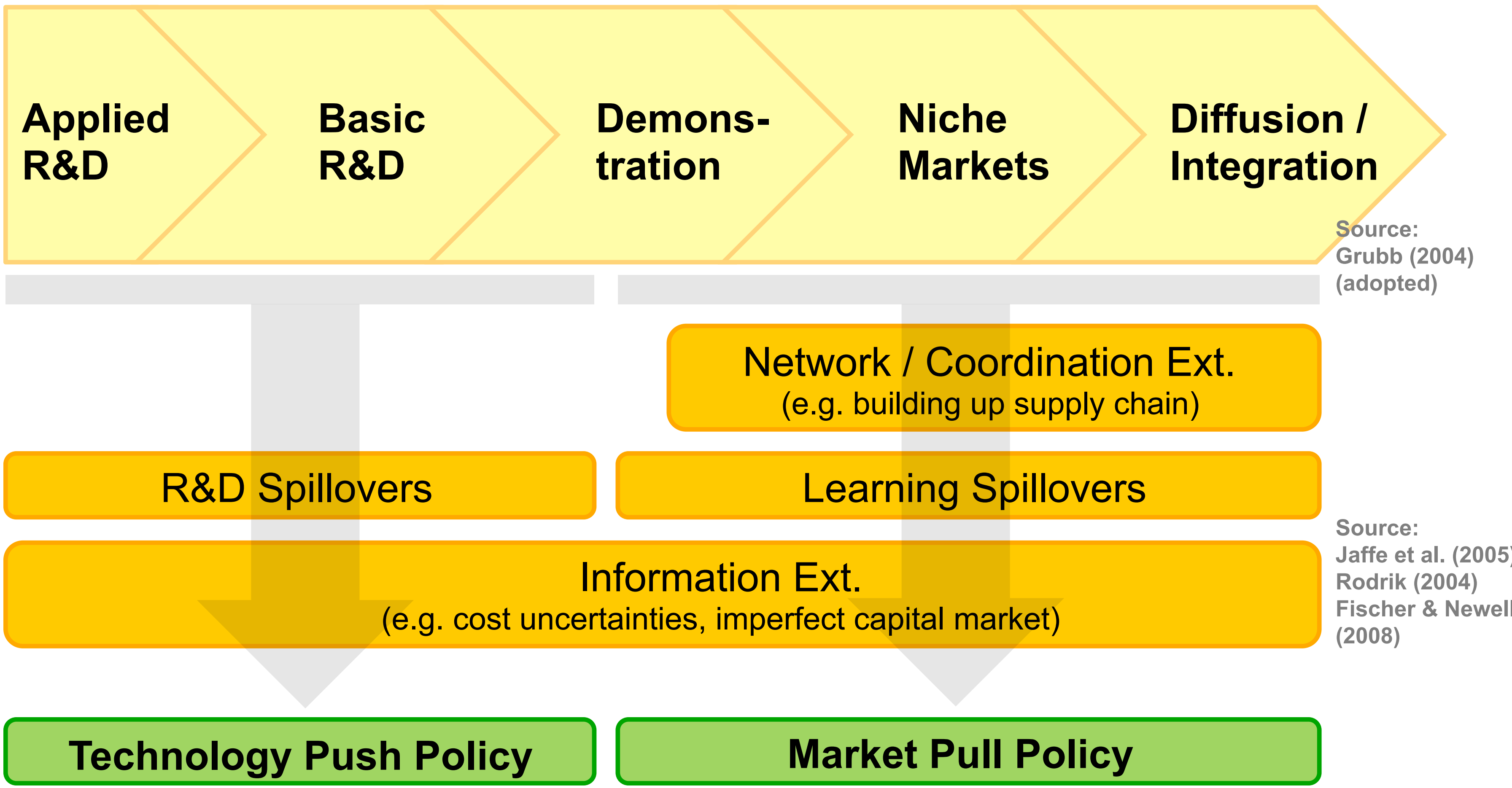
→ Possible solution: Storage, DSM, Grid, Plant flexibility

FAST: Flexibility Assessment Method (IEA 2011)



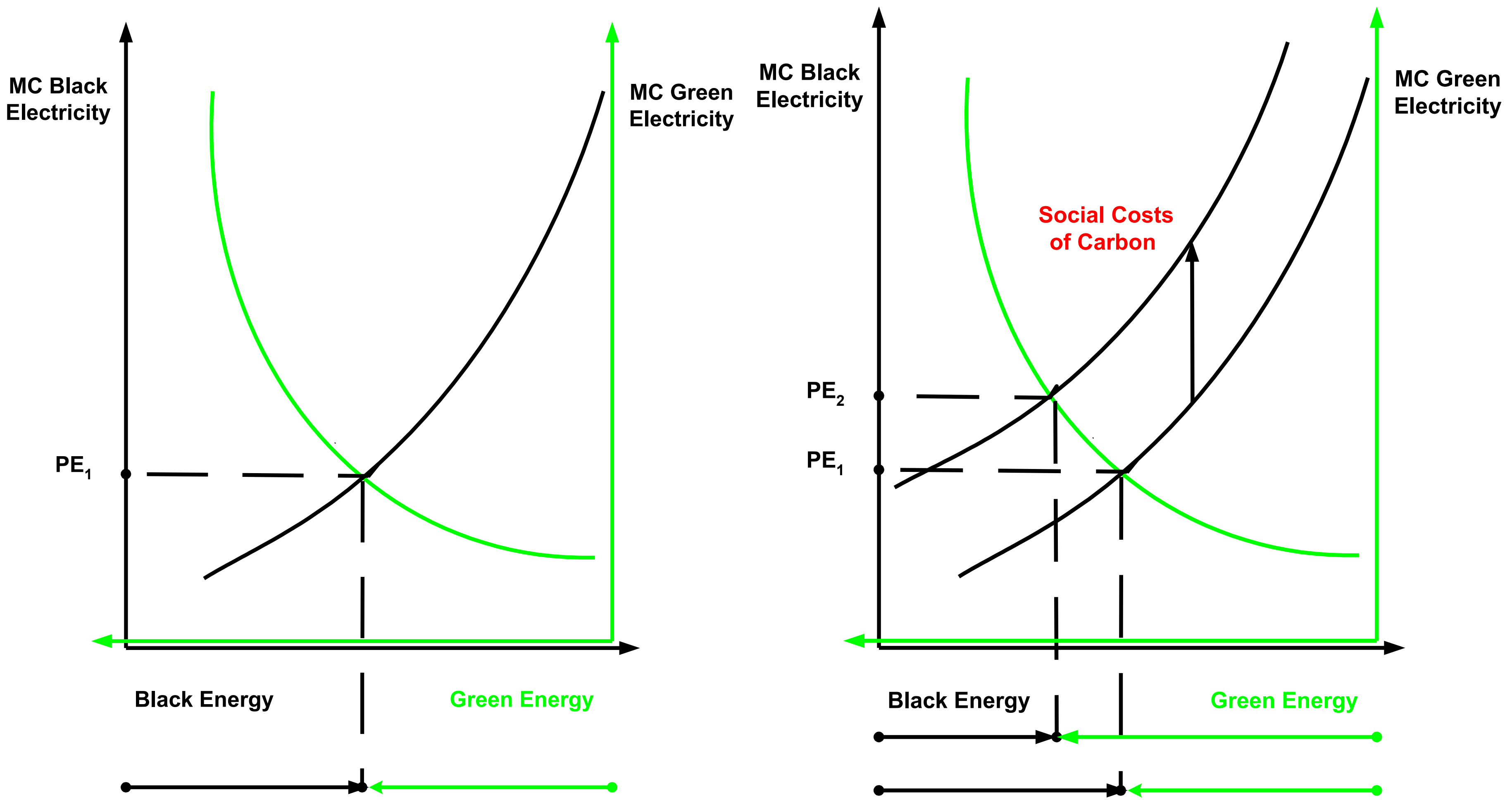
7. MARKET FAILURES – AND HOW TO CURE THEM

Externalities & Implied Policies along Innovation Chain



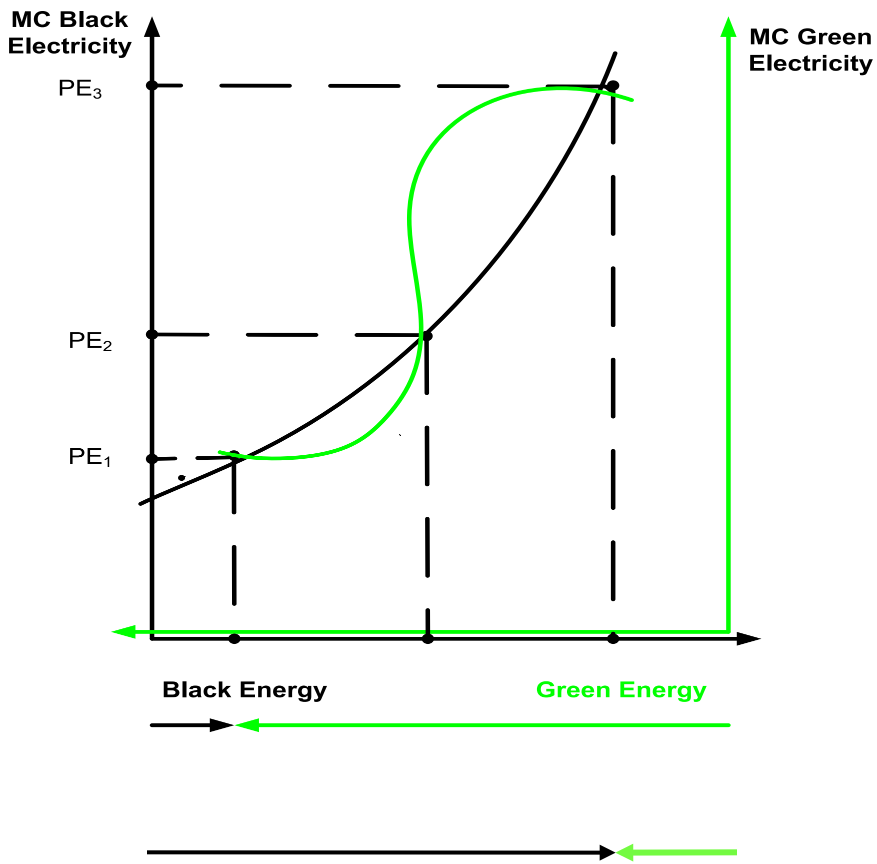
- ► **Externalities: Empirical evidence and relevance?**
- ► **Implications for RES support scheme design (FIT, CfD, TGC, Auction)?**

Case 1: Carbon Pricing is necessary and sufficient



Edenhofer et al. 2007

Case 2: Additional Promotion of Renewables is *not* reasonable



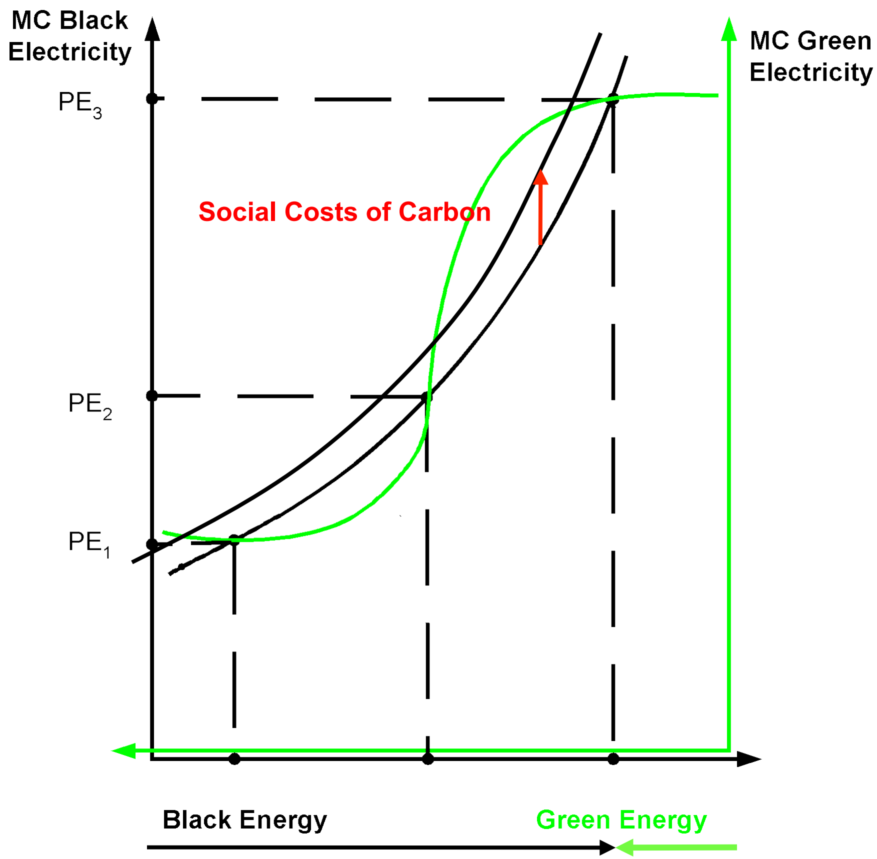
► Several stable equilibrium points (PE3 and PE1) are possible if the supply curves show a non-convex behavior
(PE_2 is not stable).

►Without additional policy support, the system will steer
towards the neighboring equilibrium point PE_3.

►$PE_3 > PE_1$:
the system is efficient.

Edenhofer et al. (2007)

Case 3: Additional Promotion of renewables *is* reasonable



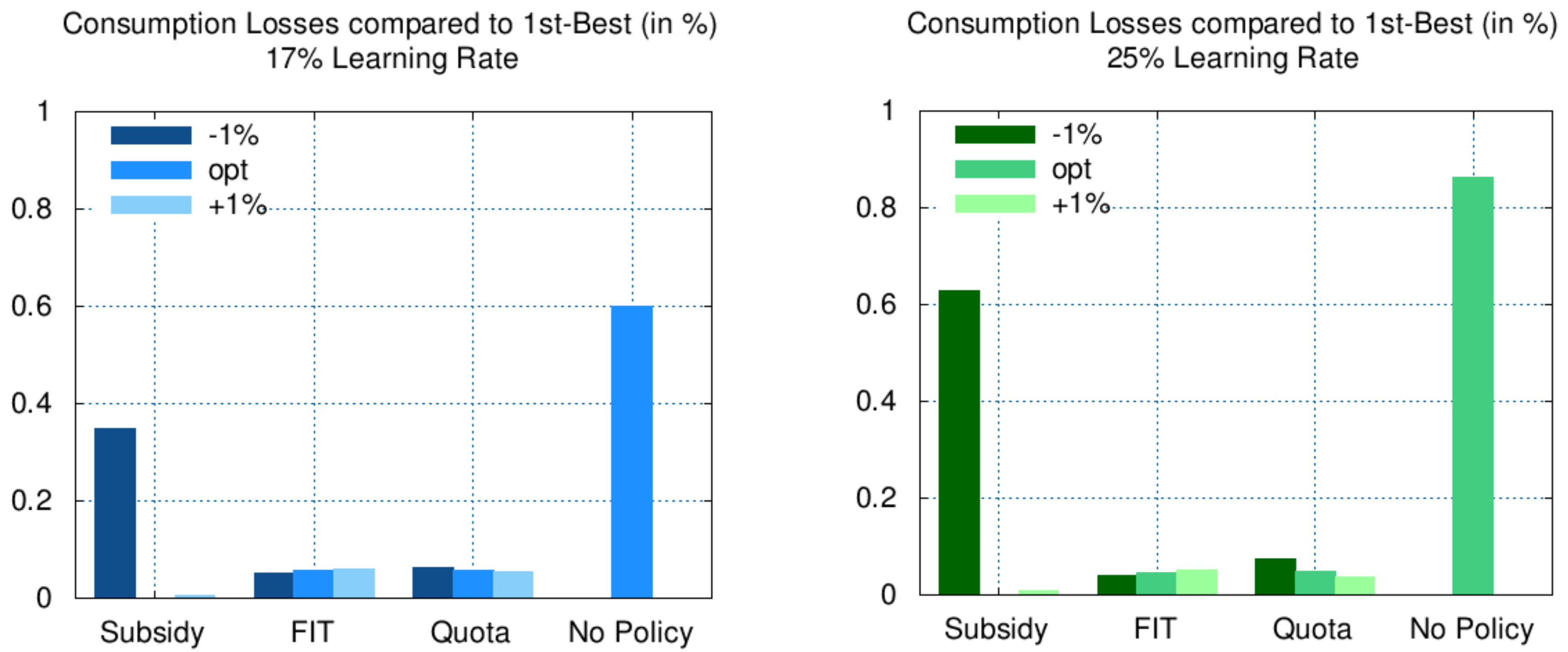
► The internalization of the social costs of energy supply (e.g. via a cap and trade system) improves the competitiveness of renewable energies

► As long as the cross-over point PE_3 does not vanish, this, however, still results in an inefficient state.

Edenhofer et al. (2007)

FROM MARKET FAILURES TO POLICY INSTRUMENTS

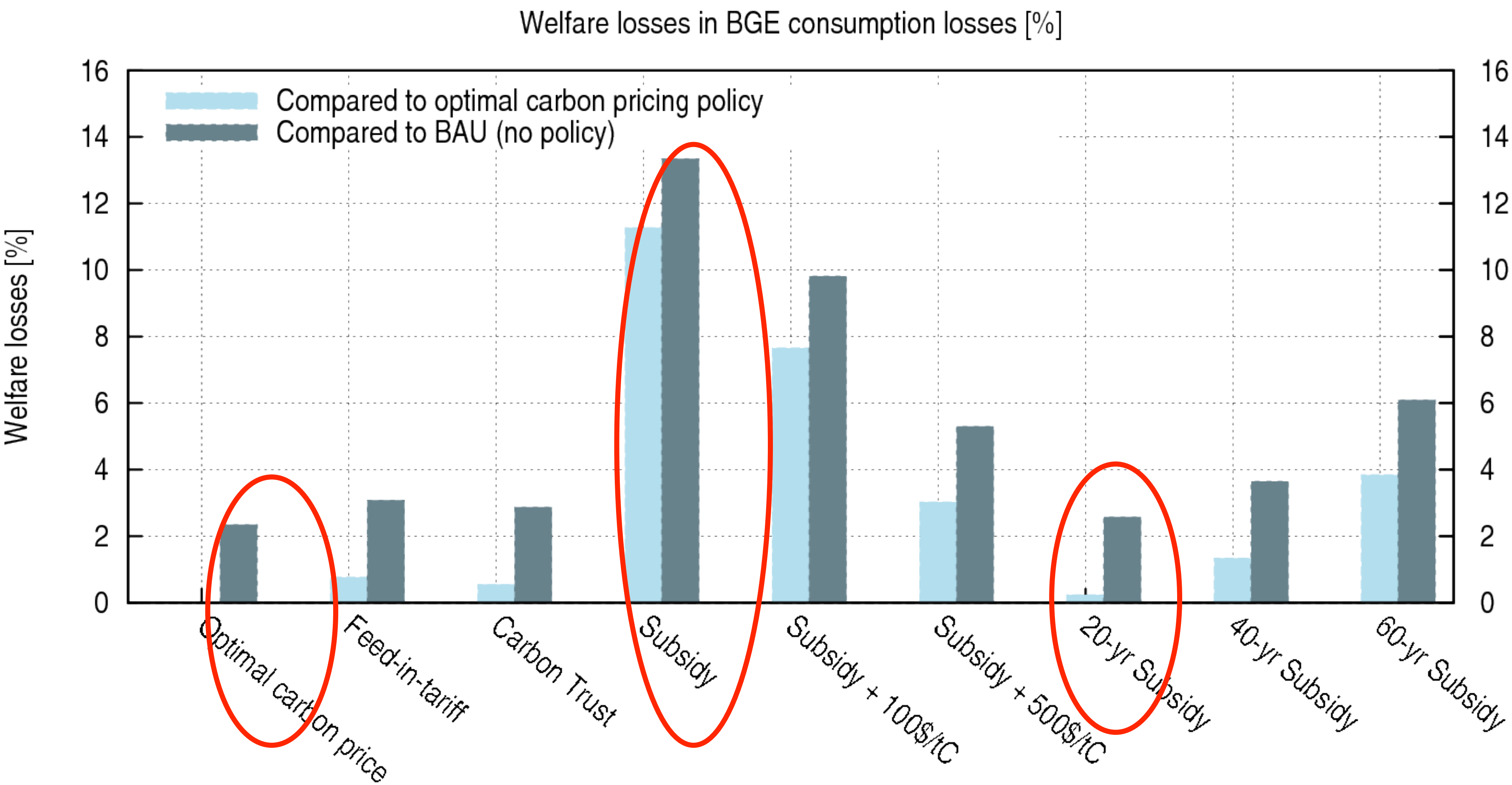
Robustness of Policy Instruments



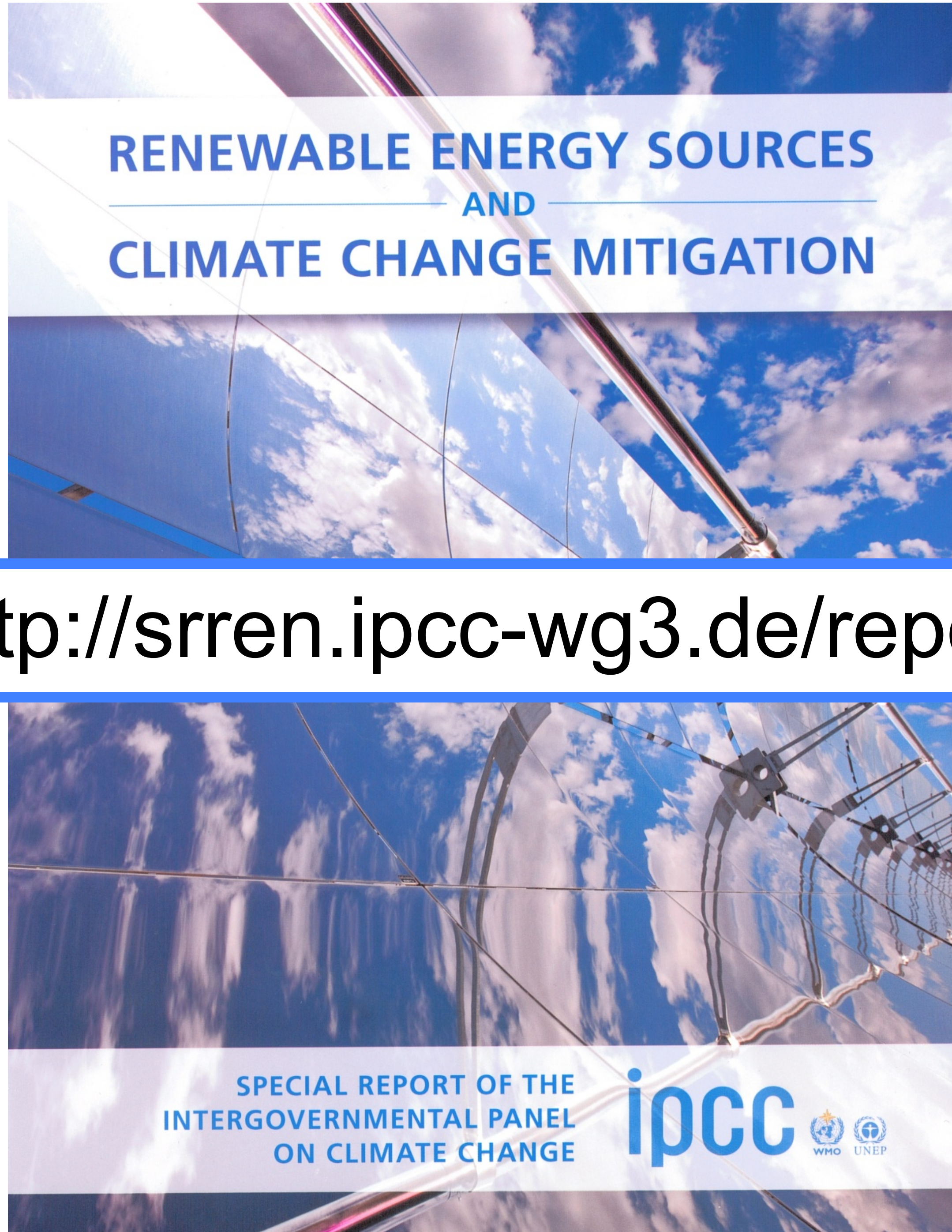
Consumption losses relative to the 1st-best optimum of optimal and “close-to-be-optimal” instruments that deviate by +1% and -1% from the optimal value.

Kalkuhl, Edenhofer, and Lessmann 2012

2nd Best-Technology Policy



Kalkuhl, Edenhofer & Lessmann 2011



http://srren.ipcc-wg3.de/report