The IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation

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Special Report on Renewable Energy Sources and Climate Change Mitigation

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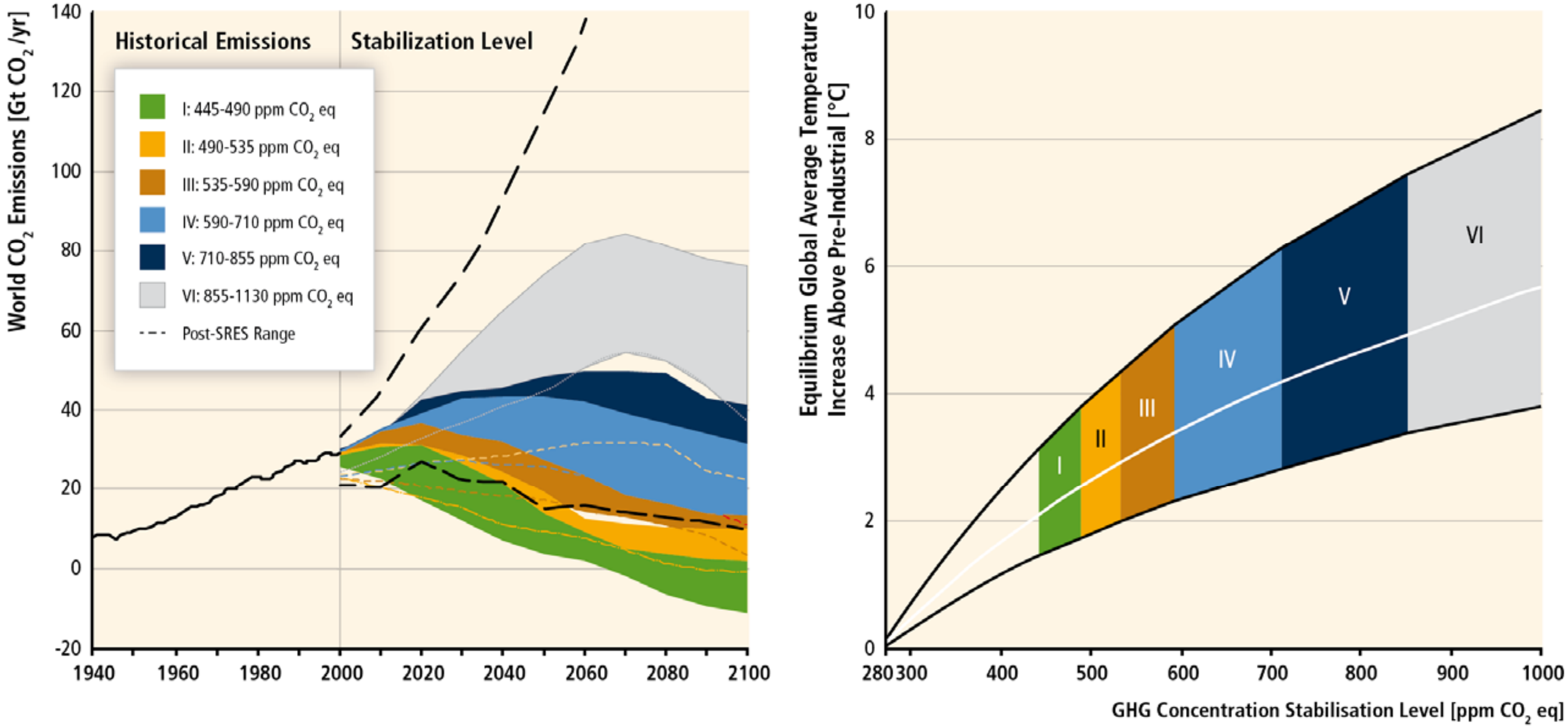
Demand for energy services is increasing.



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

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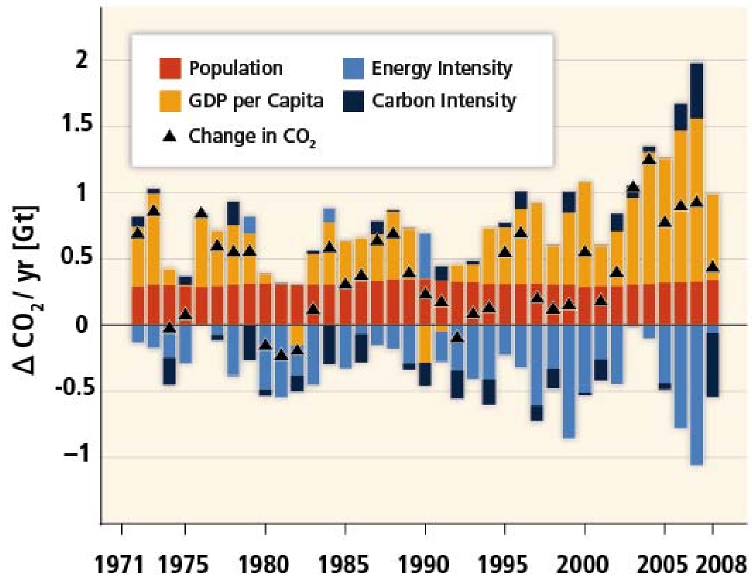
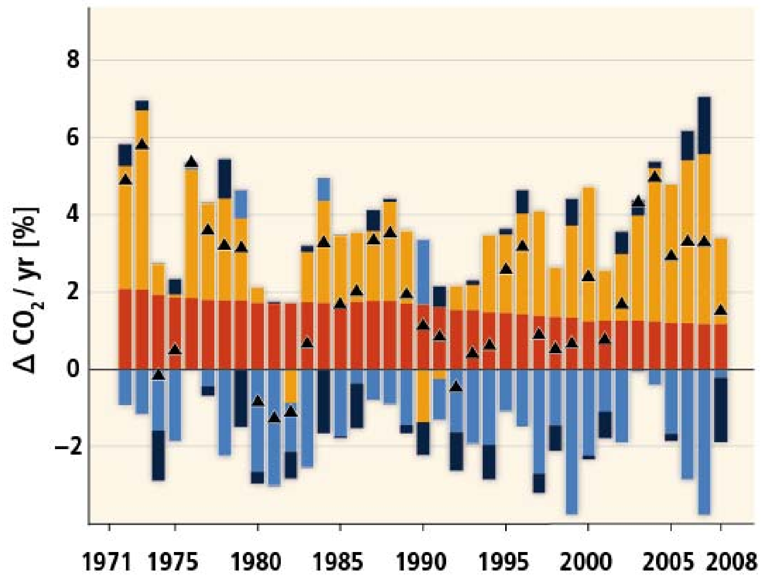
Annual change in global energy-related CO_2 emissions





Replacing fossil fuels with RE technologies lowers carbon intensity, while improved energy efficiency can lower emissions.

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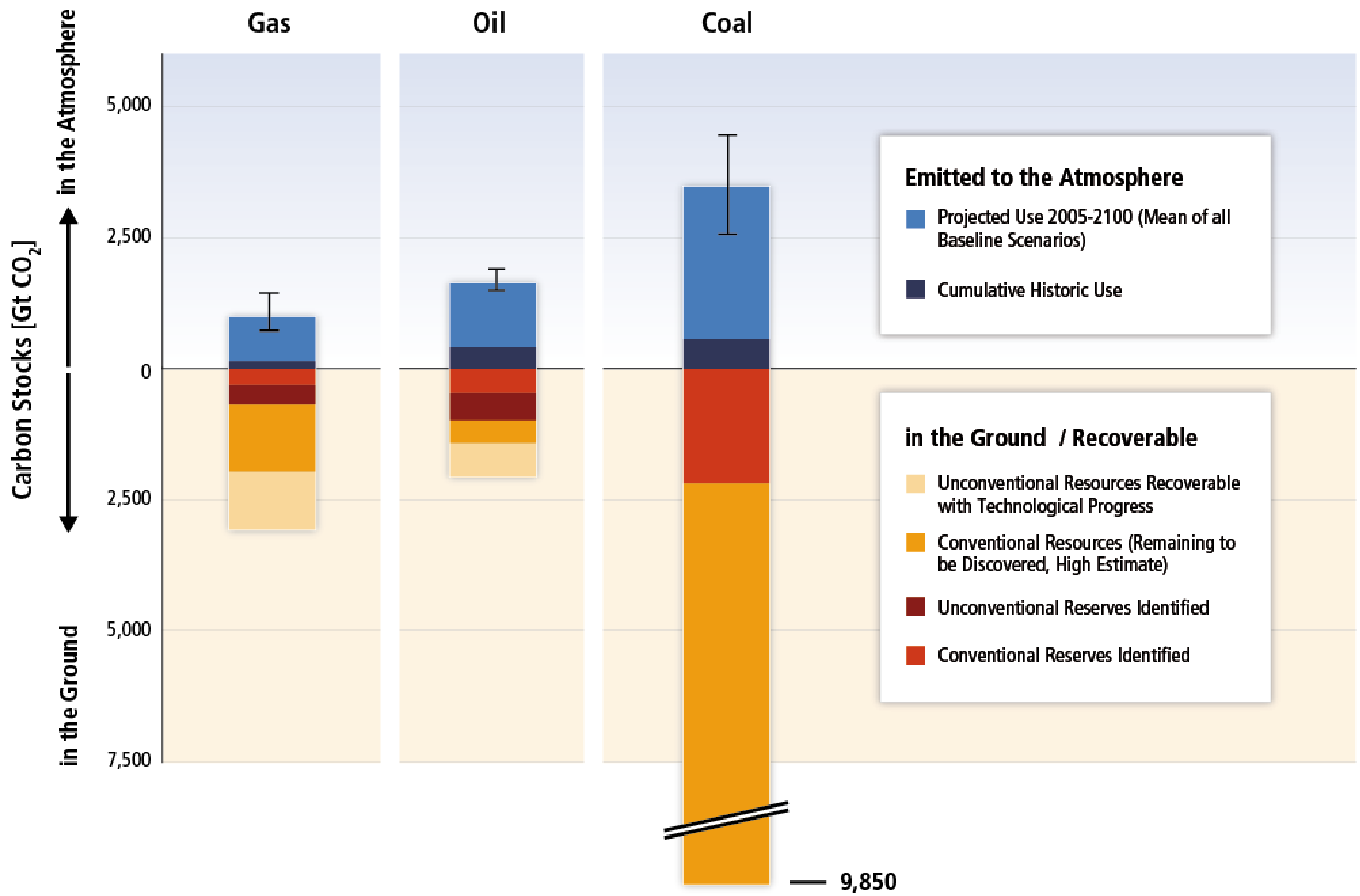
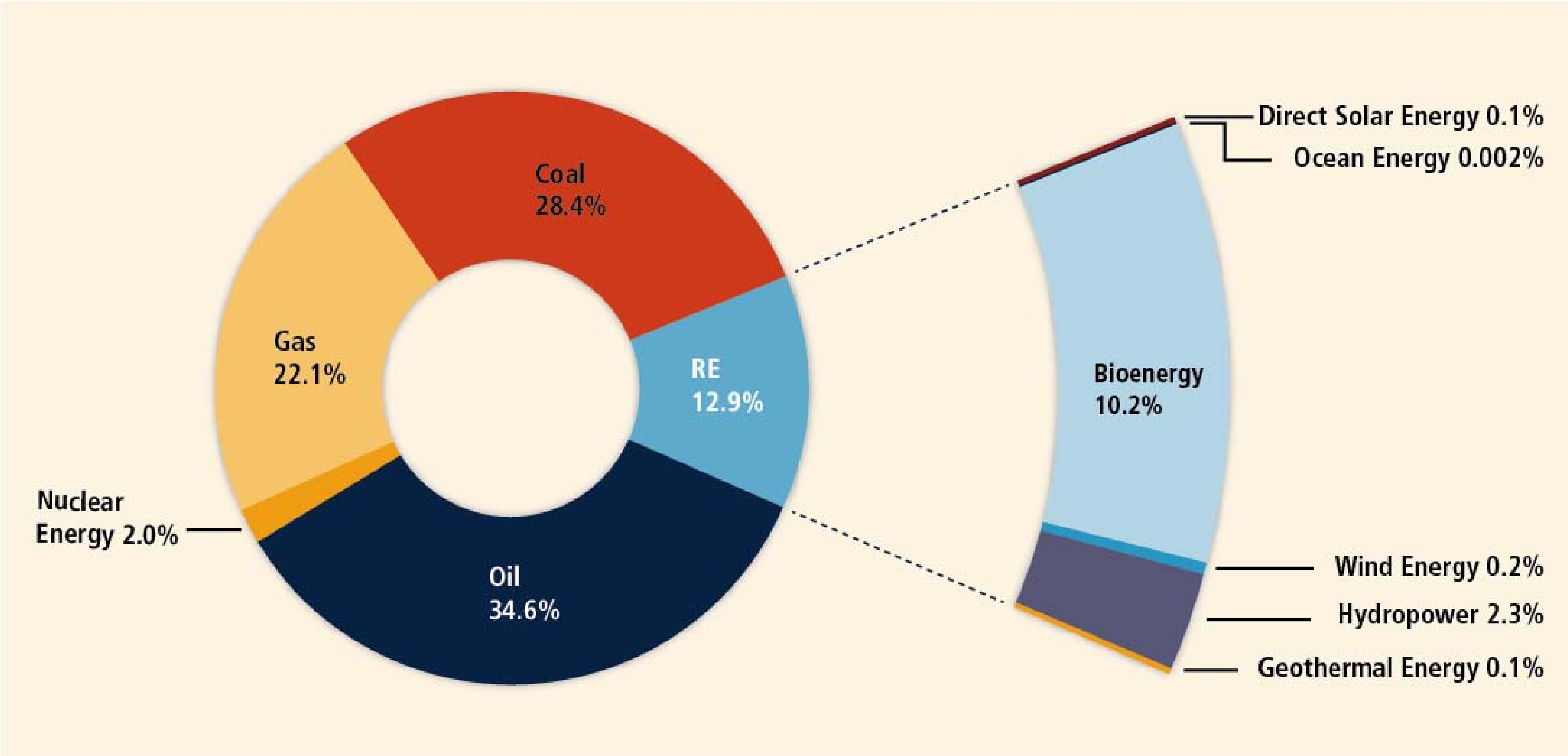
Potential emissions from remaining fossil resources could result in GHG concentration levels far above 600ppm.



The current global energy system is dominated by fossil fuels.



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

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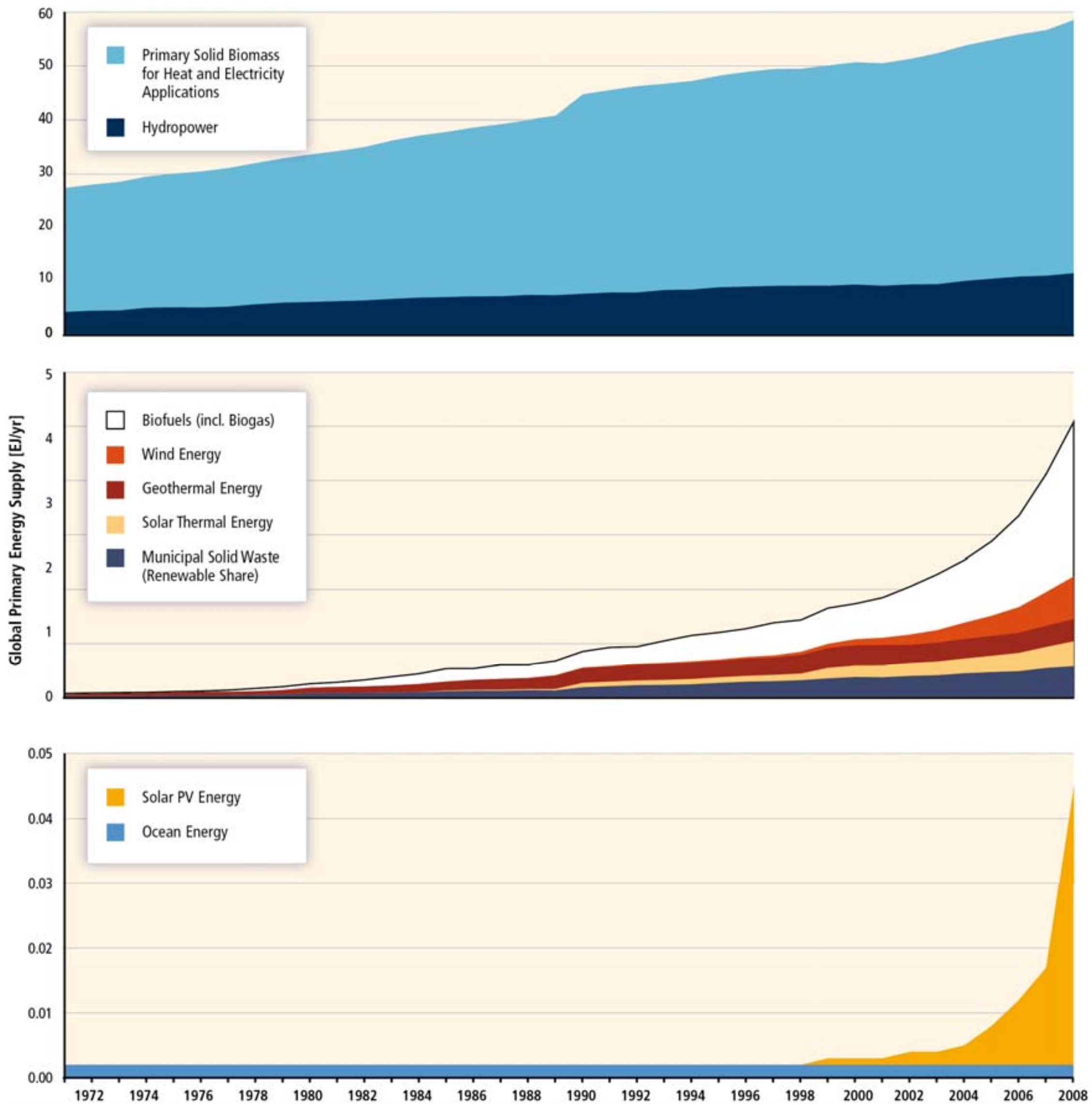
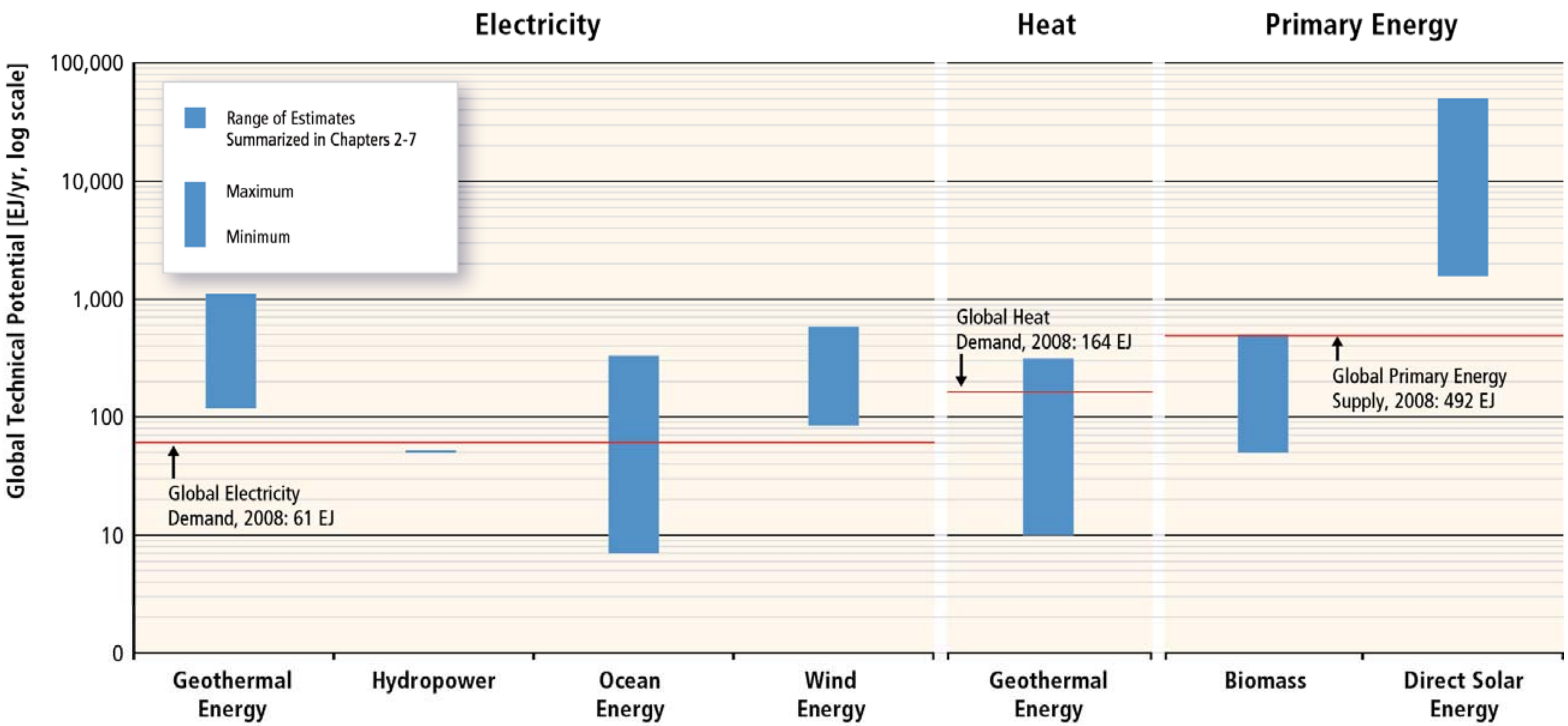
RE growth has been increasing rapidly in recent years.



140 GW of new RE power plant capacity was built in 2008-2009.

This equals 47% of all power plants built during that period.

The technical potential of renewable energy technologies to supply energy services exceeds current demands.



Range of Estimates of Global Technical Potentials

Max (in EJ/yr)	1109	52	331	580	312	500	49837
Min (in EJ/yr)	118	50	7	85	10	50	1575

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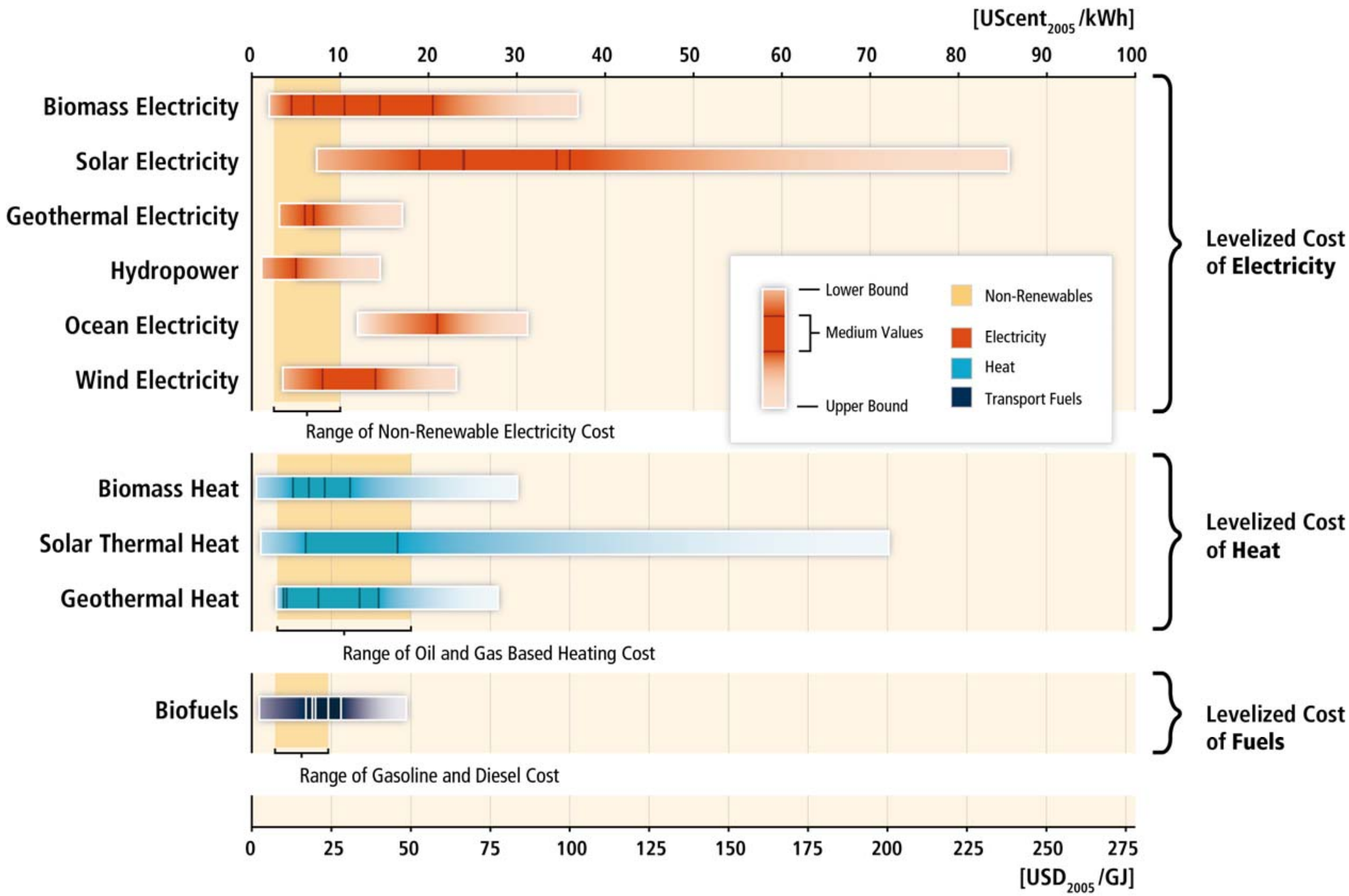
RE costs are still higher than existing energy prices, but in various settings RE is already competitive.



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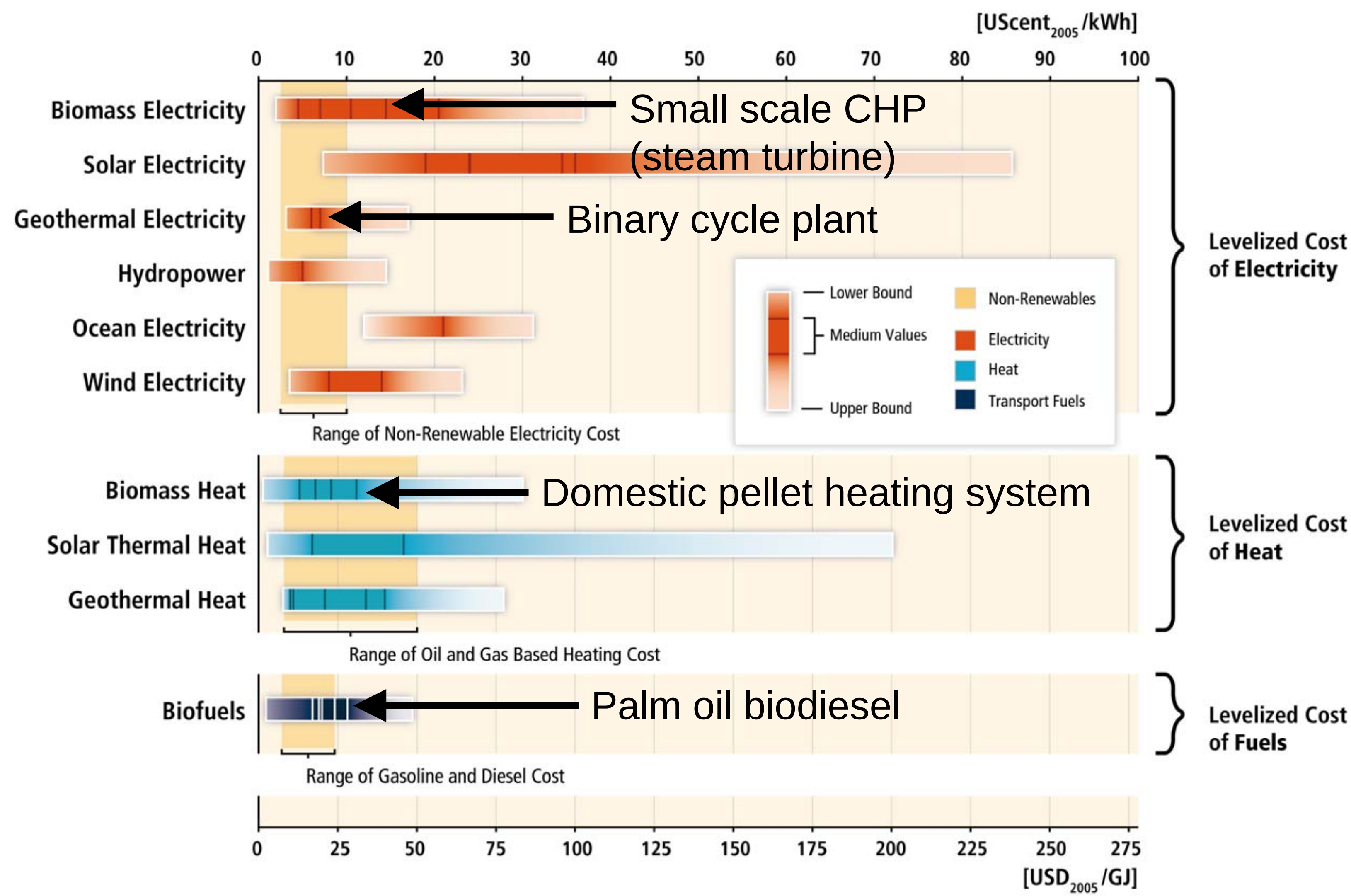


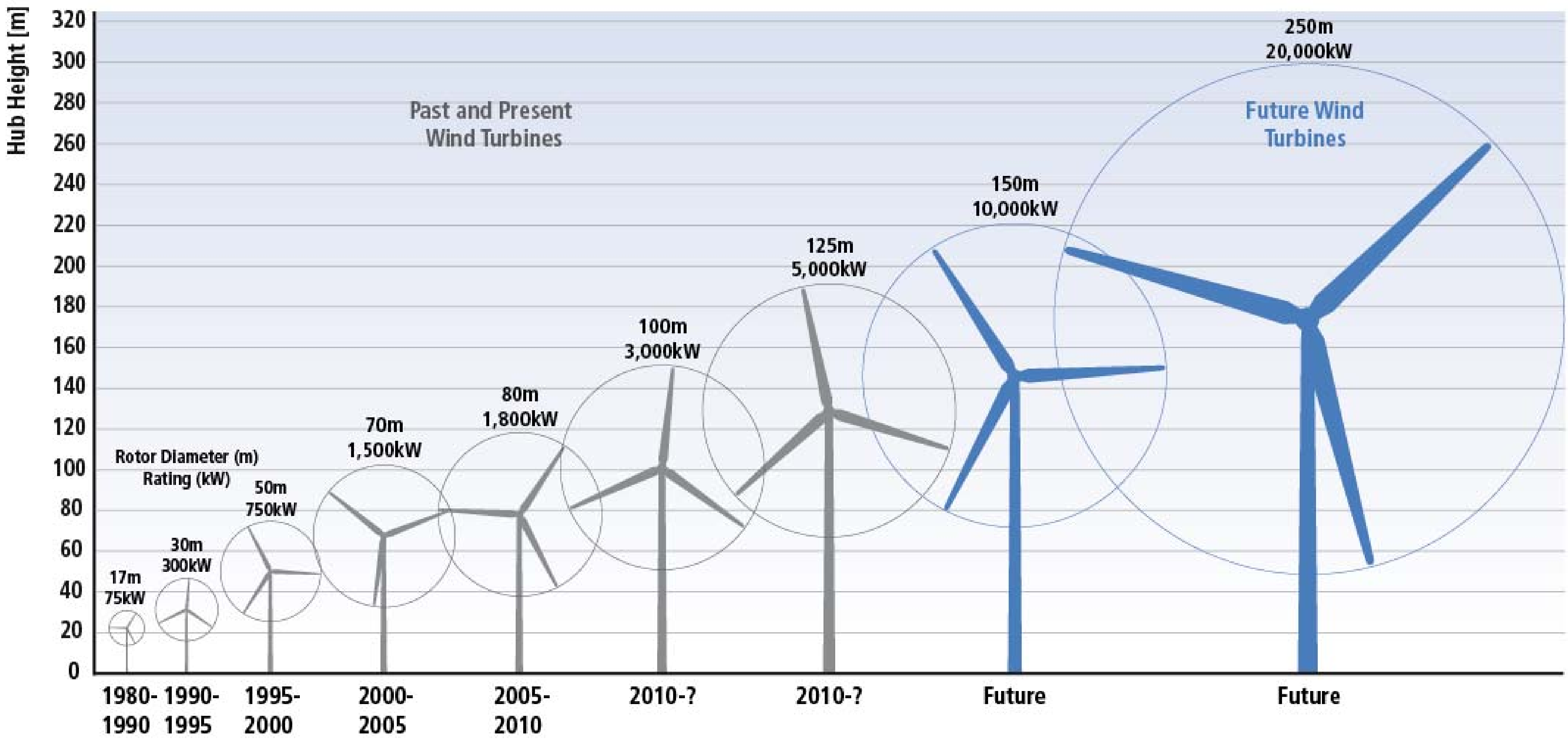
RE costs are still higher than existing energy prices, but in various settings RE is already competitive.

Notes: Medium values are shown for the following subcategories, sorted in the order as they appear in the respective ranges (from left to right):

Electricity	Heat	Transport Fuels
Biomass: 1. Cofiring 2. Small scale combined heat and power, CHP (Gasification internal combustion engine) 3. Direct dedicated stoker & CHP 4. Small scale CHP (steam turbine) 5. Small scale CHP (organic Rankine cycle) **Solar Electricity:** 1. Concentrating solar power 2. Utility-scale PV (1-axis and fixed tilt) 3. Commercial rooftop PV 4. Residential rooftop PV **Geothermal Electricity:** 1. Condensing flash plant 2. Binary cycle plant **Hydropower:** 1. All types **Ocean Electricity:** 1. Tidal barrage **Wind Electricity:** 1. Onshore 2. Offshore	**Biomass Heat:** 1. Municipal solid waste based CHP 2. Anaerobic digestion based CHP 3. Steam turbine CHP 4. Domestic pellet heating system **Solar Thermal Heat:** 1. Domestic hot water systems in China 2. Water and space heating **Geothermal Heat:** 1. Greenhouses 2. Uncovered aquaculture ponds 3. District heating 4. Geothermal heat pumps 5. Geothermal building heating	**Biofuels:** 1. Corn ethanol 2. Soy biodiesel 3. Wheat ethanol 4. Sugarcane ethanol 5. Palm oil biodiesel

The lower range of the levelized cost of energy for each RE technology is based on a combination of the most favourable input-values, whereas the upper range is based on a combination of the least favourable input values. Reference ranges in the figure background for non-renewable electricity options are indicative of the levelized cost of centralized non-renewable electricity generation. Reference ranges for heat are indicative of recent costs for oil and gas based heat supply options. Reference ranges for transport fuels are based on recent crude oil spot prices of USD 40 to 130/barrel and corresponding diesel and gasoline costs, excluding taxes.

Technical Advancements: For instance growth in size of typical commercial wind turbines.



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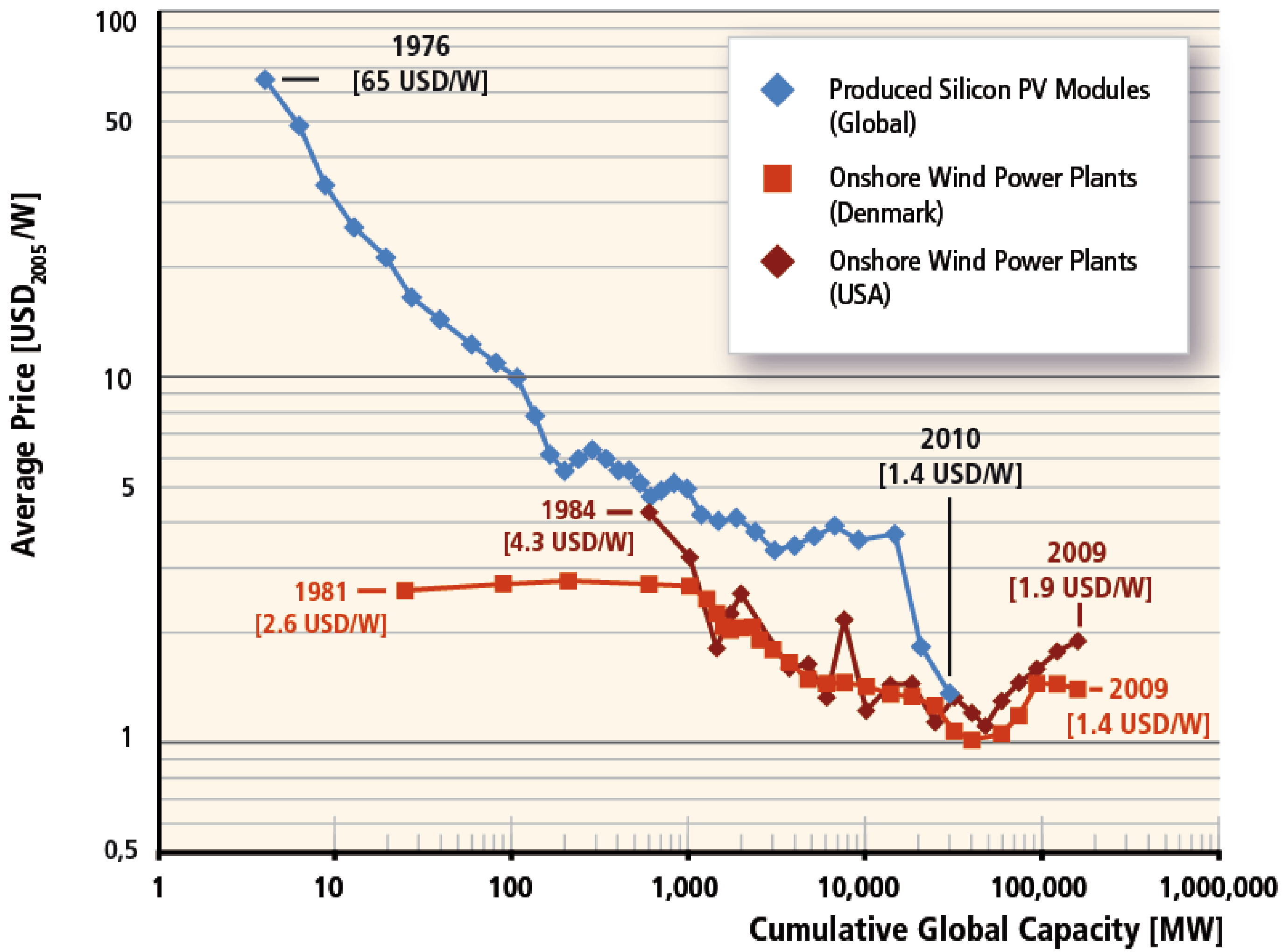
RE costs have declined in the past and further declines can be expected in the future.



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)

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

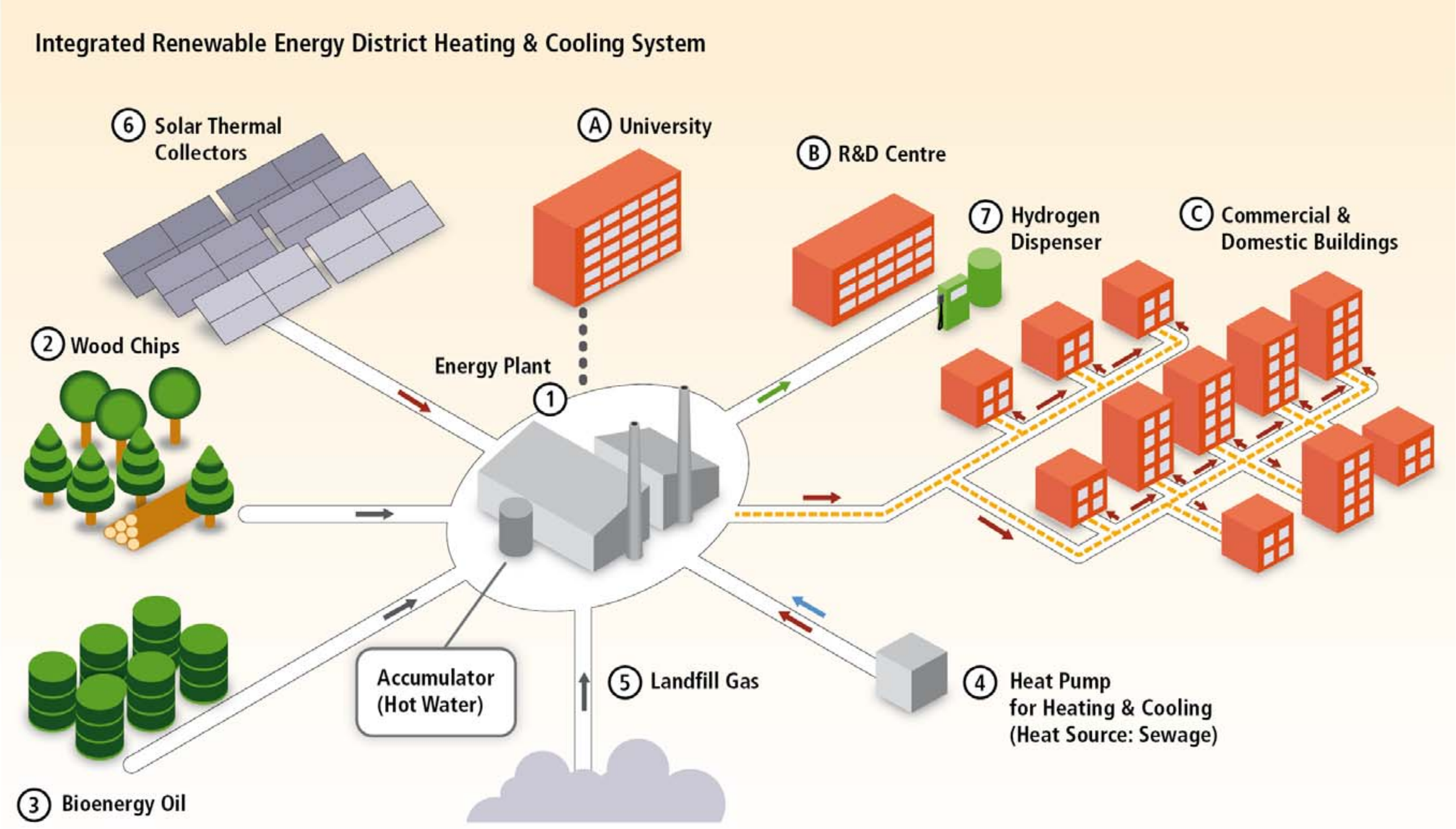
Technology		[...]	Capacity credit range
		[...]	%
Bioenergy		[...]	Similar to thermal and CHP
Direct solar energy	PV	[...]	<25–75
	CSP with thermal storage*	[...]	90
Geothermal energy		[...]	Similar to thermal
Hydropower	Run of river	[...]	0–90
	Reservoir	[...]	Similar to thermal
Ocean energy	Tidal range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

**Few, if any, fundamental technical limits exist to the integration of a majority share of RE,
but advancements in several areas are needed.**

- Transmission and distribution infrastructure
- Generation flexibility
- Energy storage technologies
- Demand side management
- Improved forecasting and operational planning methods

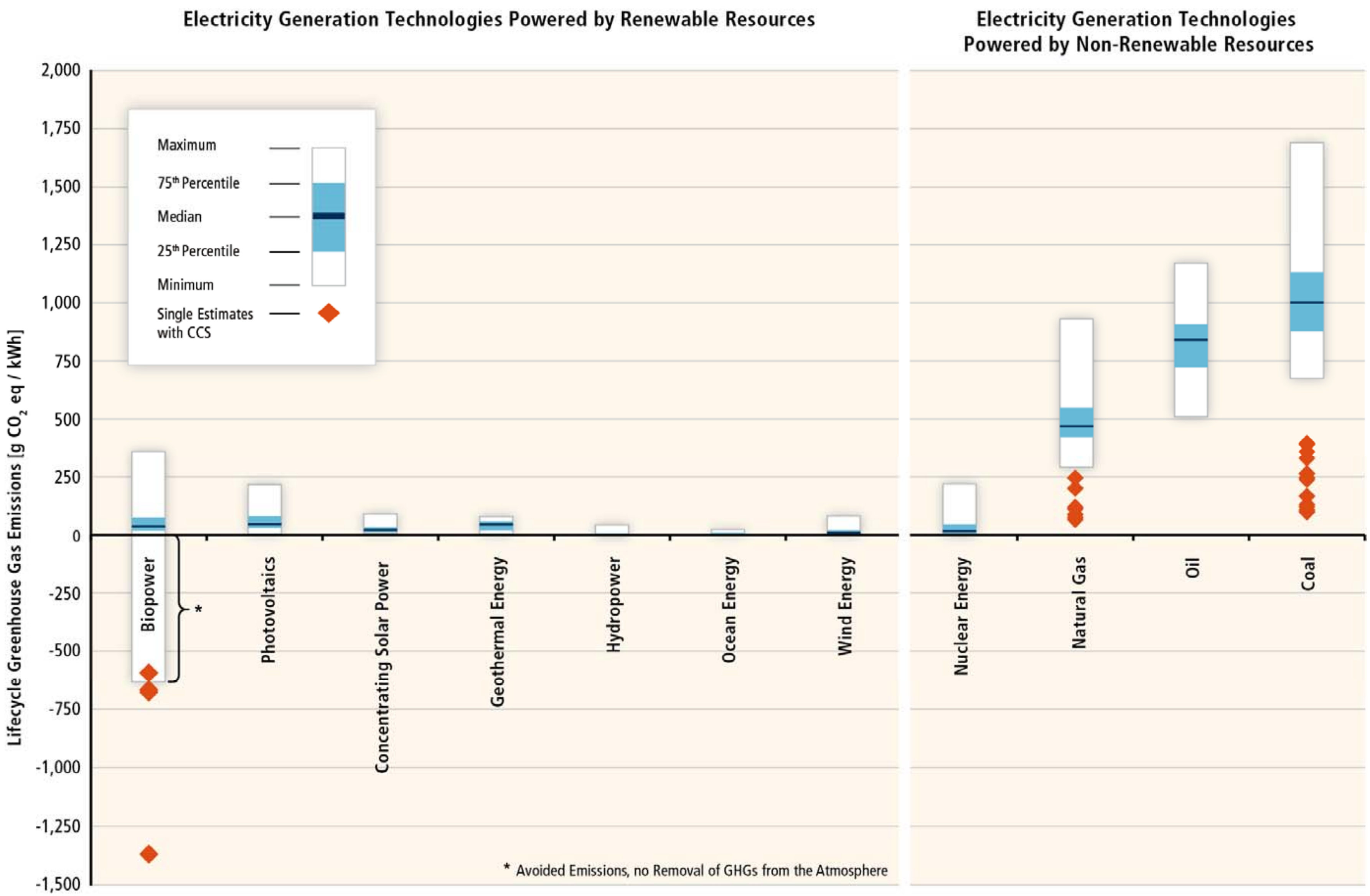
An integrated RE-based energy plant in Lillestrøm, Norway, supplying commercial and domestic buildings



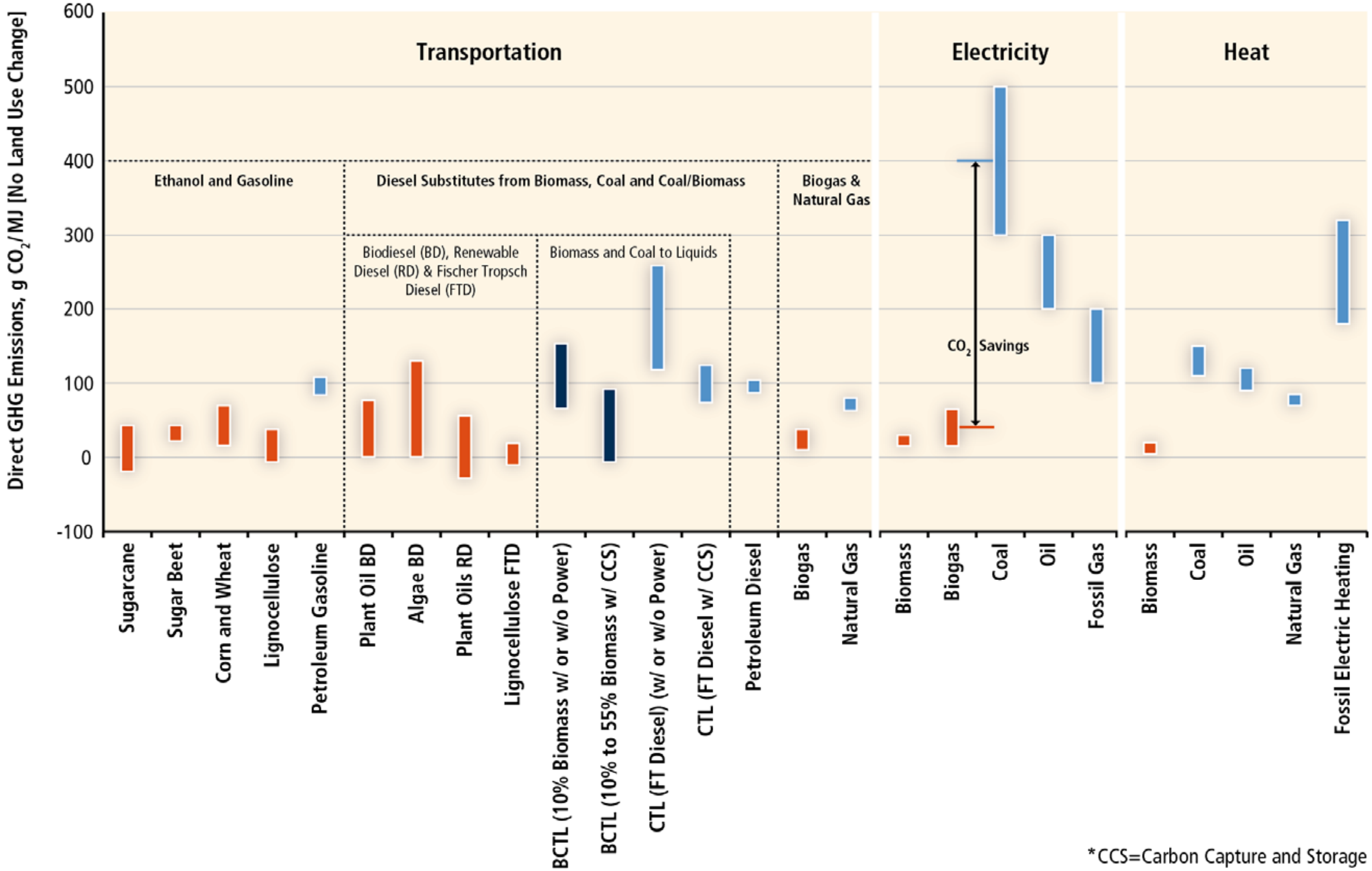
RE can contribute to sustainable development.

- RE can accelerate access to energy, particularly for the 1.4 billion people without access to electricity and the additional 1.3 billion people using traditional biomass
- RE deployment can reduce vulnerability to supply disruptions and market volatility
- Low risk of severe accidents
- Environmental and health benefits

Lifecycle GHG emissions of RE technologies are, in general, considerably lower than those of fossil fuel options.

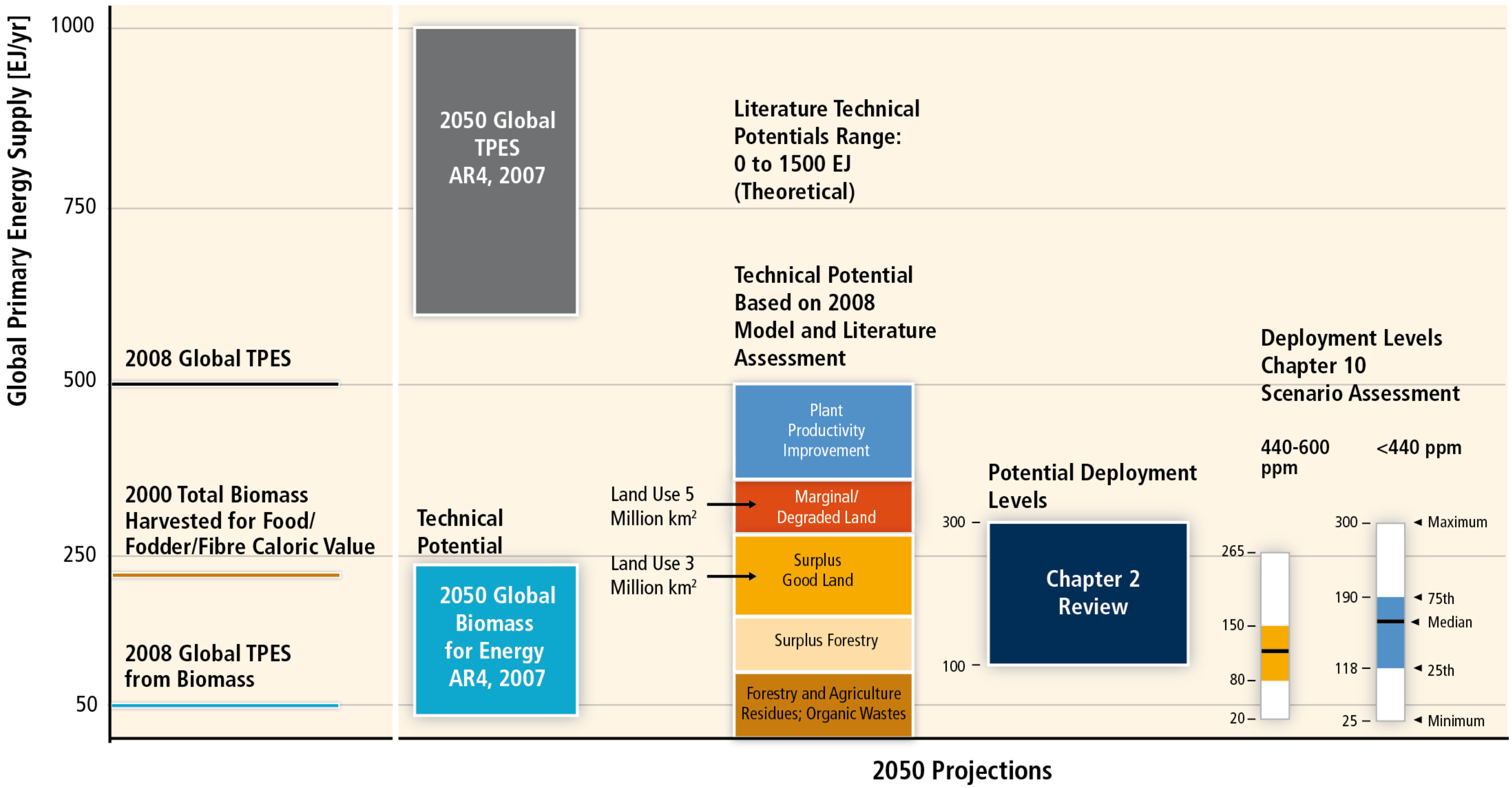


GHG emissions from modern bioenergy chains compared to fossil fuel energy systems, excluding land-use change effects.



*CCS=Carbon Capture and Storage

Terrestrial biomass for energy



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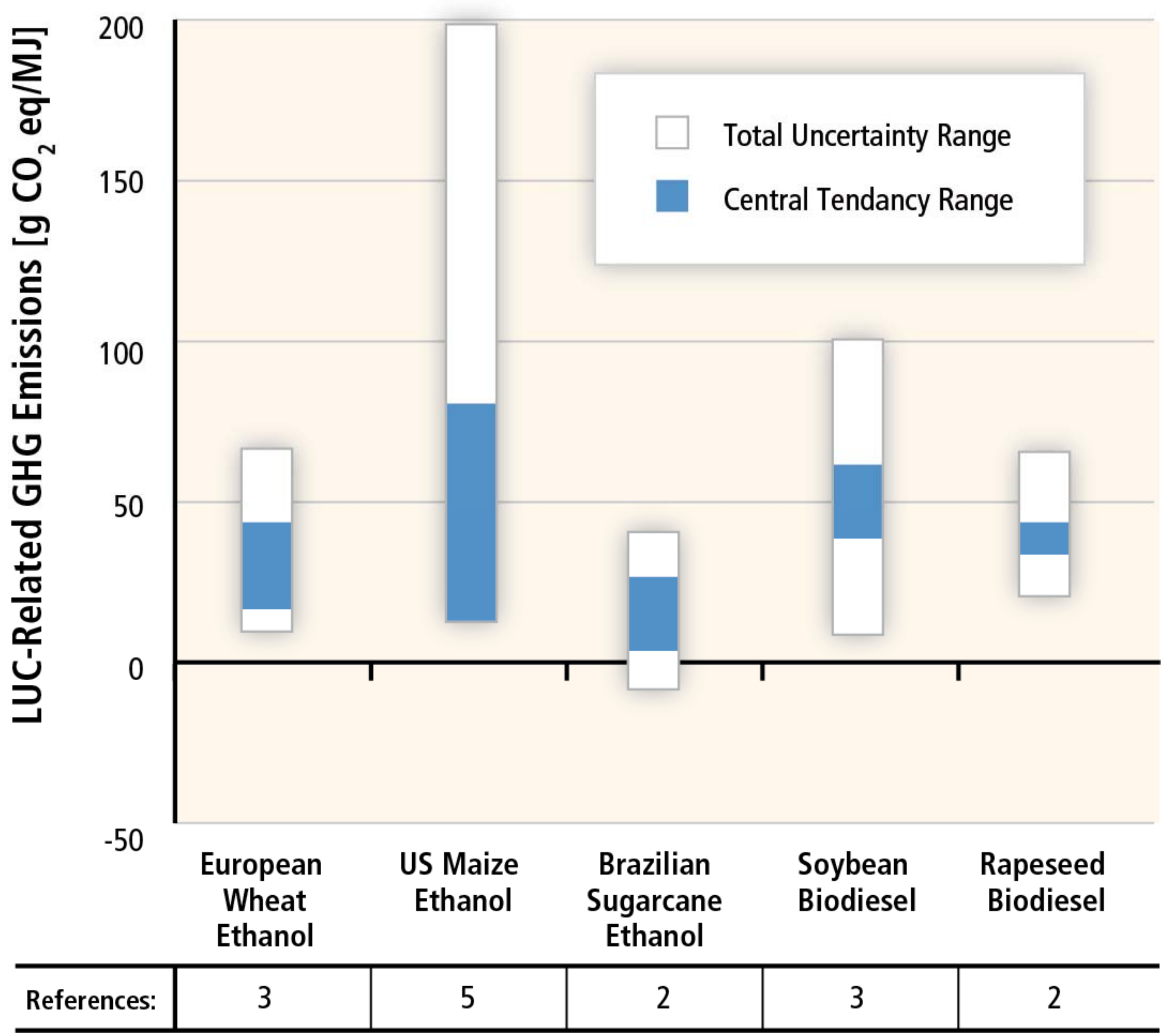
Land-use change and bioenergy

- The positive greenhouse gas balance of biofuels can be affected by direct and indirect land-use changes.

- Proper governance of land use, zoning, and choice of biomass production systems are key challenges for policy makers

Direct and indirect land use GHG emissions



High and low bioenergy scenarios both possible – whether sustainable depends on deployment

IPCC SRES Scenarios

Material/Economic

(A1)
Future world of very rapid economic growth, global population peaks in mid-century and declines thereafter, and introduces rapidly new and more efficient technologies.

(A2)
Very heterogeneous future world characterized by self reliance and preservation of local identities. Fragmented and slower technological change.

	(A1)	(A2)
Food Trade:	Maximal High	Low
Meat Consumption:	High	High
Technology Development:	High	Low
Food Crop Fertilization:	Very High	High
Crop Intensity Growth:	High	Low
2050 Population (Billion):	8.7	11.3
2100 Population (Billion):	7.1	15.1
Relative 2100 GDP:	100%	46%

Globally Oriented | Regionally Oriented

(B1)
Future world convergent in global population, with rapid change in economic structures toward a service and information economy, low material intensity, and clean and resource efficient technologies.

(B2)
World emphasis is on local solutions to economic, social and environmental sustainability. Less rapid and more diverse technological change.

	(B1)	(B2)
Food Trade:	High	Very Low
Meat Consumption:	Low	Low
Technology Development:	High	Low
Food Crop Fertilization:	Low	Low
Crop Intensity Growth:	High	Low
2050 Population (Billion):	8.7	9.4
2100 Population (Billion):	7.1	10.4
Relative 2100 GDP:	61%	44%

Environment/Social

Material/Economic

2050 Bioenergy Storylines

Globally Oriented — Regionally Oriented

Environment/Social

(A1) ~300 EJ/Poor Governance

Key Preconditions

- High energy demand results in high energy prices and drive strong biomass demand.
- Limited oversight on biomass production and use, largely driven by market demand.
- Fully liberalized markets for bioenergy as well as in agriculture as a whole.
- Strong technology development leading to increased demand for biochemicals and advanced transport fuels from biomass.

Key Impacts

- Production emphasis is on higher quality land, converted pastures, etc.
- Biomass produced and used in large scale operations, limiting small farmers' benefits.
- Large scale global trade and conversion capacity developed in major seaports.
- Competition with conventional agriculture for the better quality land, driving up food prices and increasing pressure on forest resources.
- GHG benefits overall but sub-optimal due to significant iLUC effects.

(A2) ~100 EJ/Poor Governance

Key Preconditions

- High fossil fuel prices expected due to high demand and limited innovation, which pushes demand for biofuels use from an energy security perspective.
- Increased biomass demand directly affects food markets.

Key Impacts

- Increased biomass demand partly covered by residues and wastes, partly by annual crops.
- Additional crop demand leads to significant iLUC effects and biodiversity impacts.
- Overall increased food prices linked to high oil prices.
- Limited net GHG benefits.
- Sub-optimal socio-economic benefits.

(B1) ~300 EJ/Good Governance

Key Preconditions

- Well working sustainability frameworks and strong policies are implemented.
- Well developed bioenergy markets.
- Progressive technology development, e.g. biorefineries, new generation biofuels and multiple products, successful use of degraded lands.
- Developing countries succeed in transitioning to higher efficiency technologies and implement biorefineries at scales compatible with available resources.
- Satellite processing emerges.

Key Impacts

- 35% biomass from residues and wastes, 25% from marginal/degraded lands and 40% from arable and pasture lands (~3 and ~1 million km², respectively).
- Moderate energy price (notably oil) due to strong increase of biomass and biofuels supply.
- Food and fuel conflicts largely avoided due to strong land-use planning and alignment of bioenergy production capacity with efficiency increases in agriculture and livestock management.
- Soil quality and soil carbon improve and negative biodiversity impacts are minimised using diverse and mixed cropping systems.

(B2) ~100 EJ/Good Governance

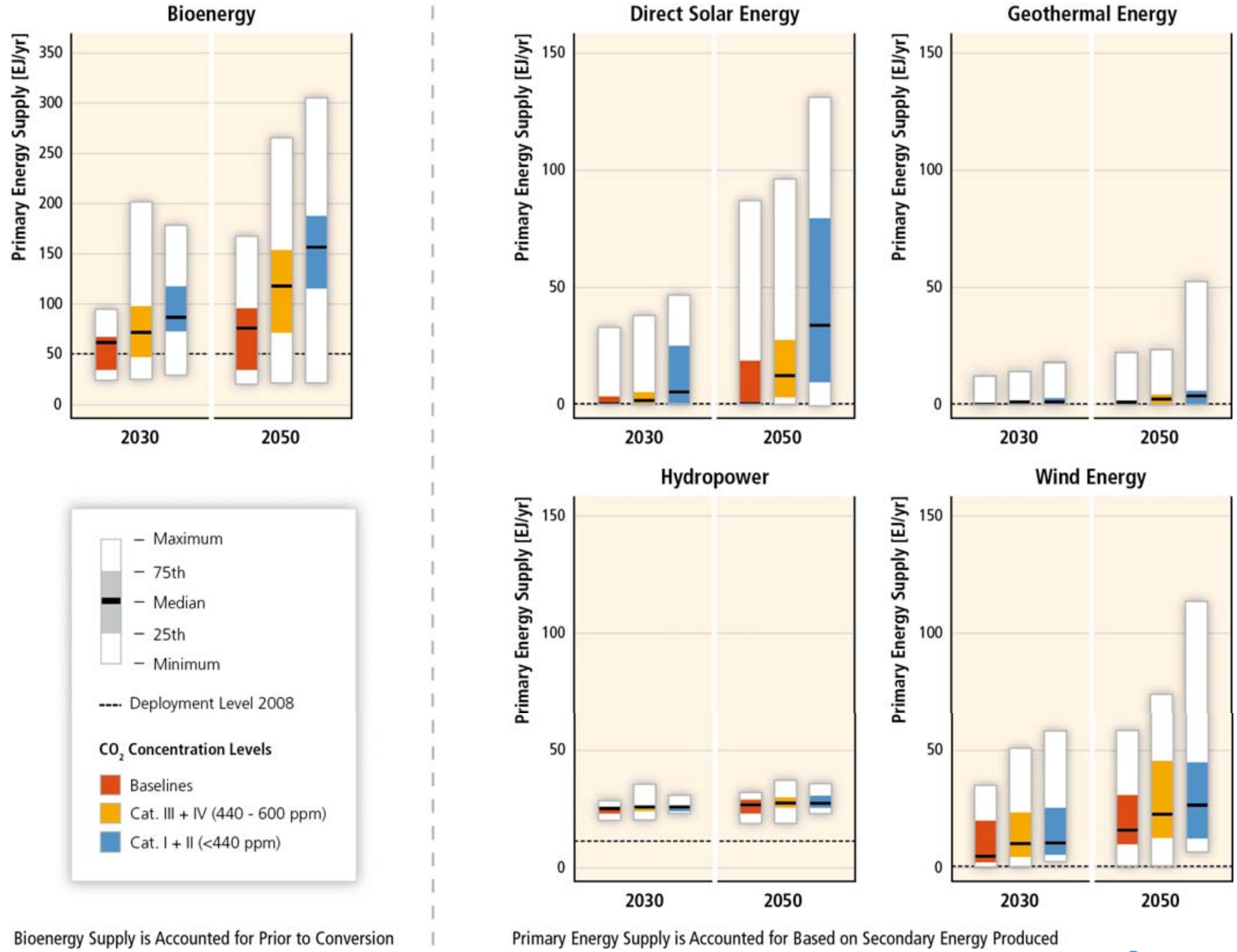
Key Preconditions

- Focus on smaller scale technologies, utilization of residues, waste streams and smaller scale cropping schemes (e.g. Jathropha) and a large array of specific cropping schemes.
- International trade is constrained and trade barriers remain.
- Effective national policy frameworks control bioenergy deployment, put priority on food and optimize biomass production and use for specific regional conditions.

Key Impacts

- Biomass comes from residues, organic wastes and cultivation on more marginal lands.
- Smaller scale bioenergy applications developed specially and used locally.
- Substantial benefits provided for rural economies in terms of employment and diversified energy sources providing services.
- Food, land-use and nature conservation conflicts are largely avoided.
- Significant GHG mitigation benefits are constrained by limited bioenergy deployment.
- Transport sector still uses a high share of petroleum to cover energy needs.

RE deployment increases in scenarios with lower greenhouse gas concentration stabilization levels.



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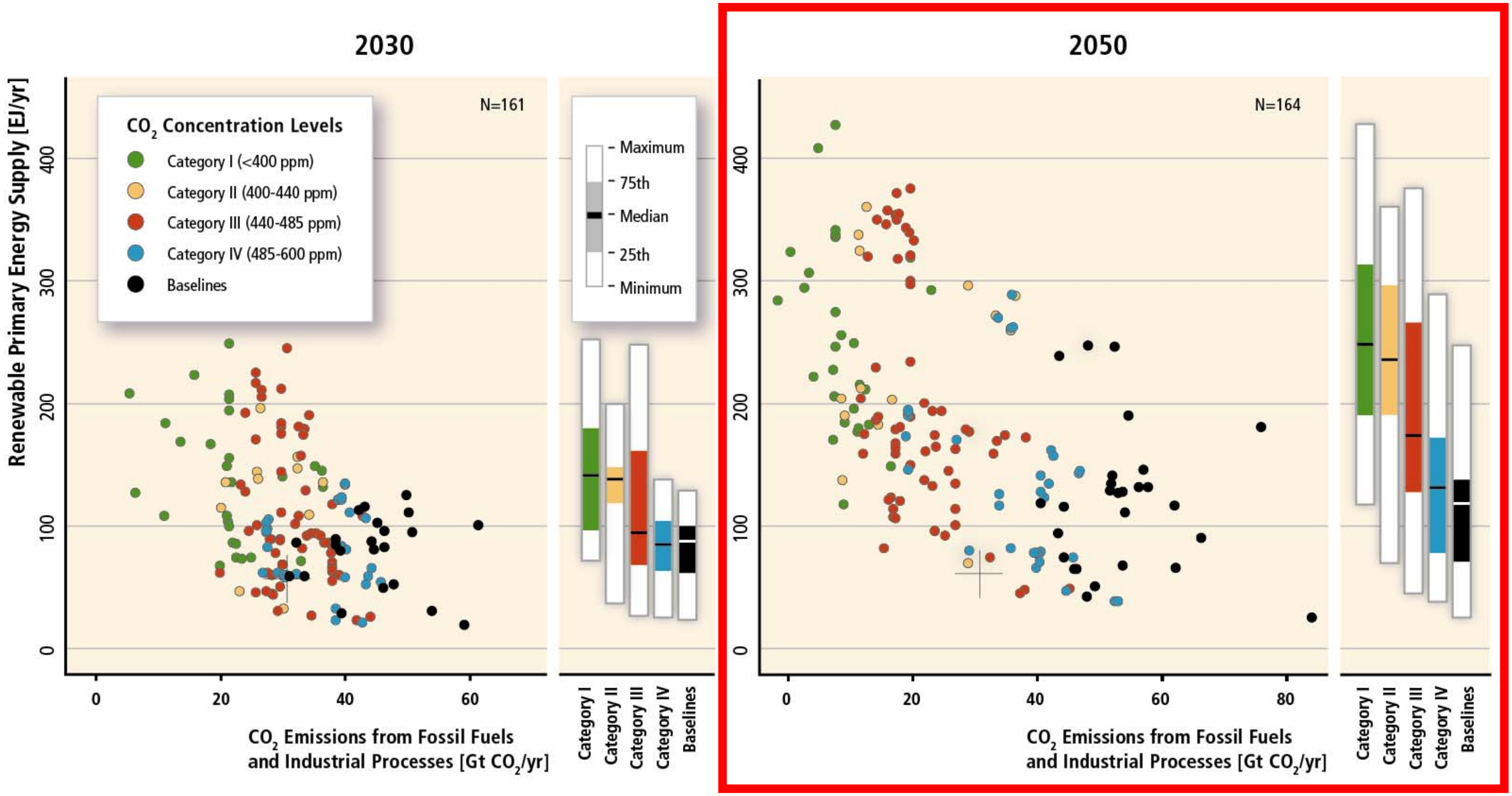
Global RE primary energy supply from 164 long-term scenarios versus fossil and industrial CO_2 emissions.



SRREN SPM, Figure SPM.9

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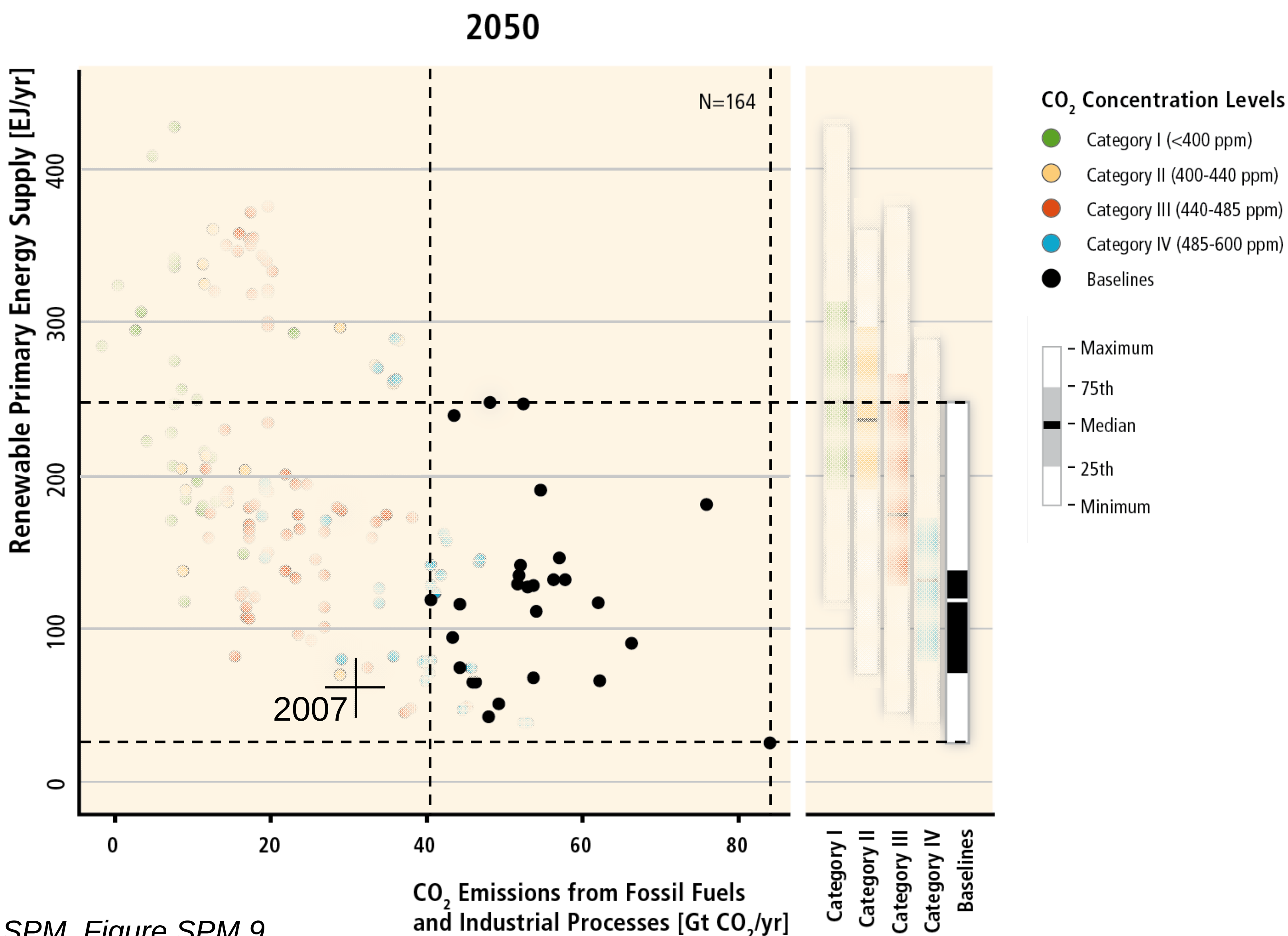
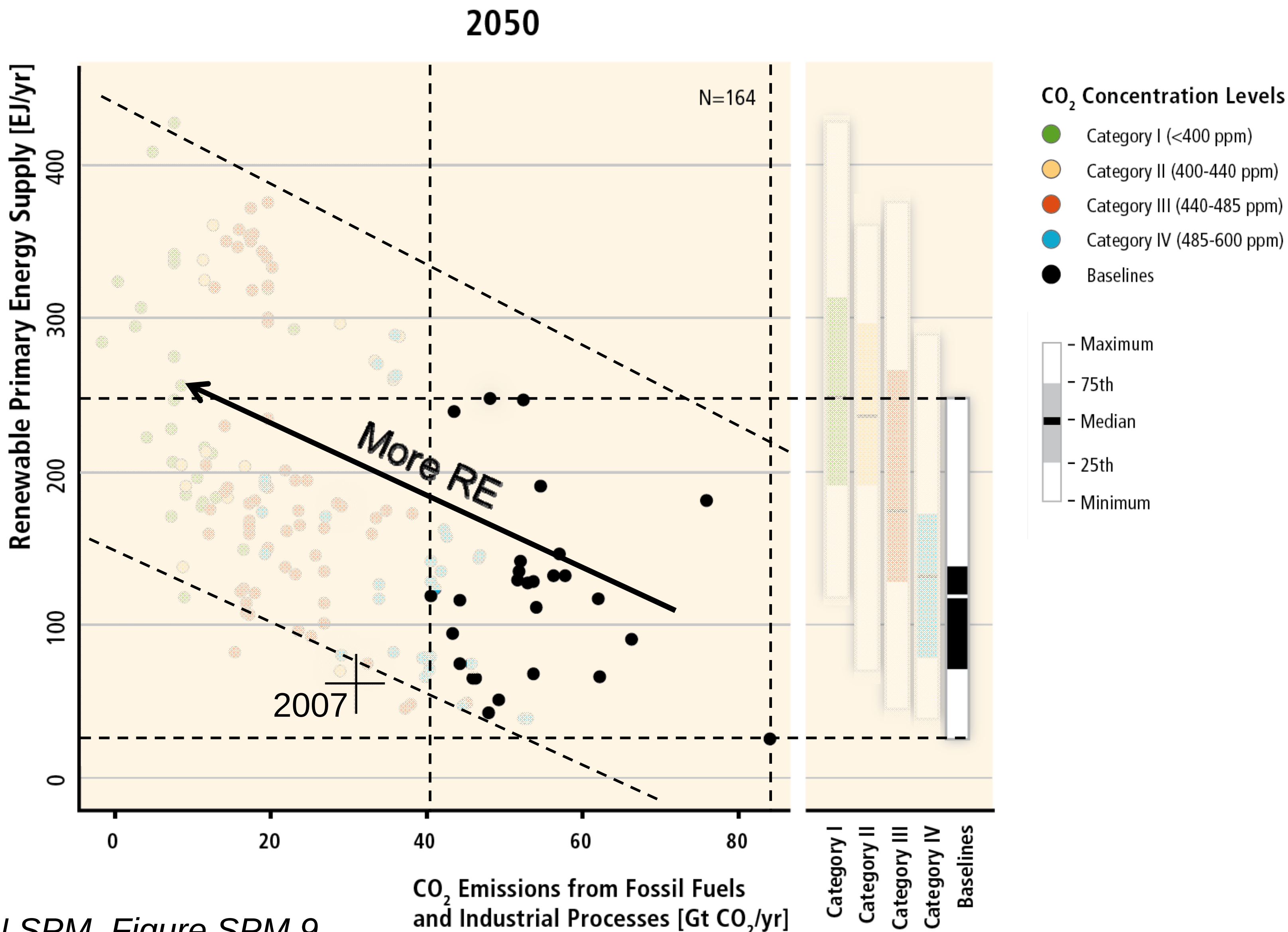
Global RE primary energy supply from 164 long-term scenarios versus fossil and industrial CO_2 emissions.



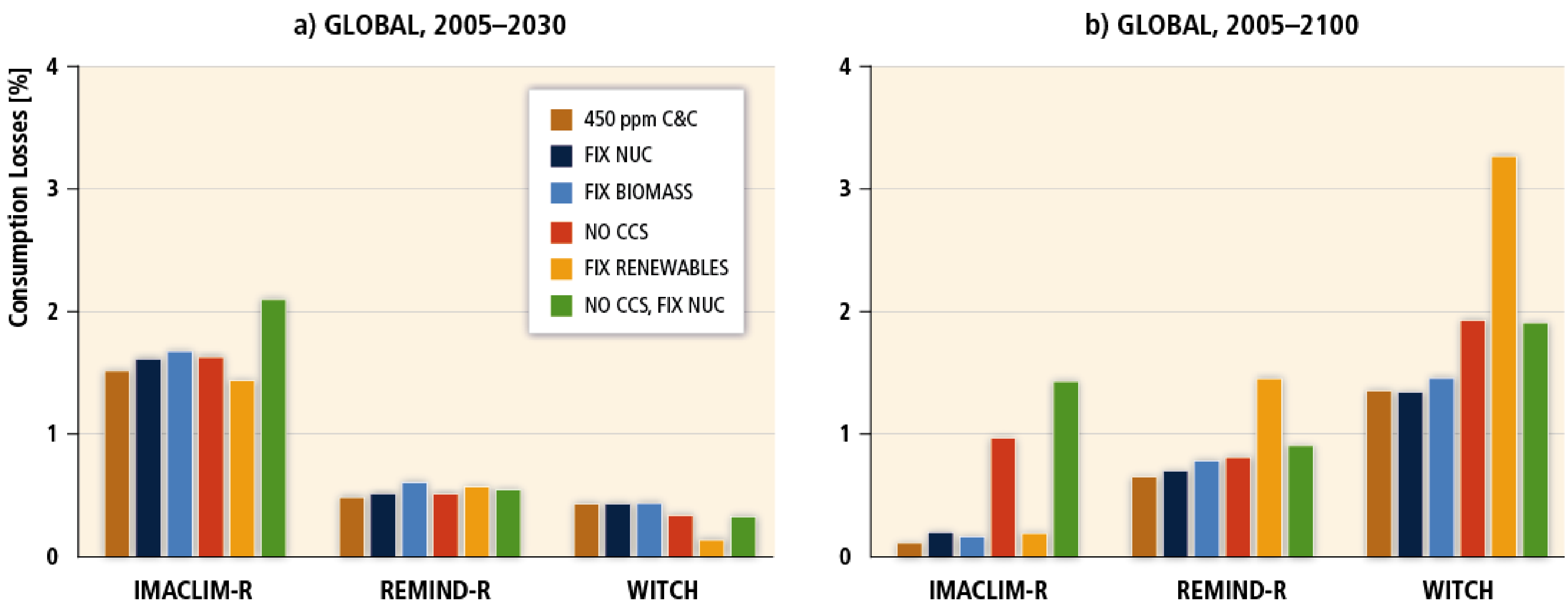
SRREN SPM, Figure SPM.9

Global RE primary energy supply from 164 long-term scenarios versus fossil and industrial CO_2 emissions.



SRREN SPM, Figure SPM.9

Macroeconomic costs



Edenhofer et al. (2011)

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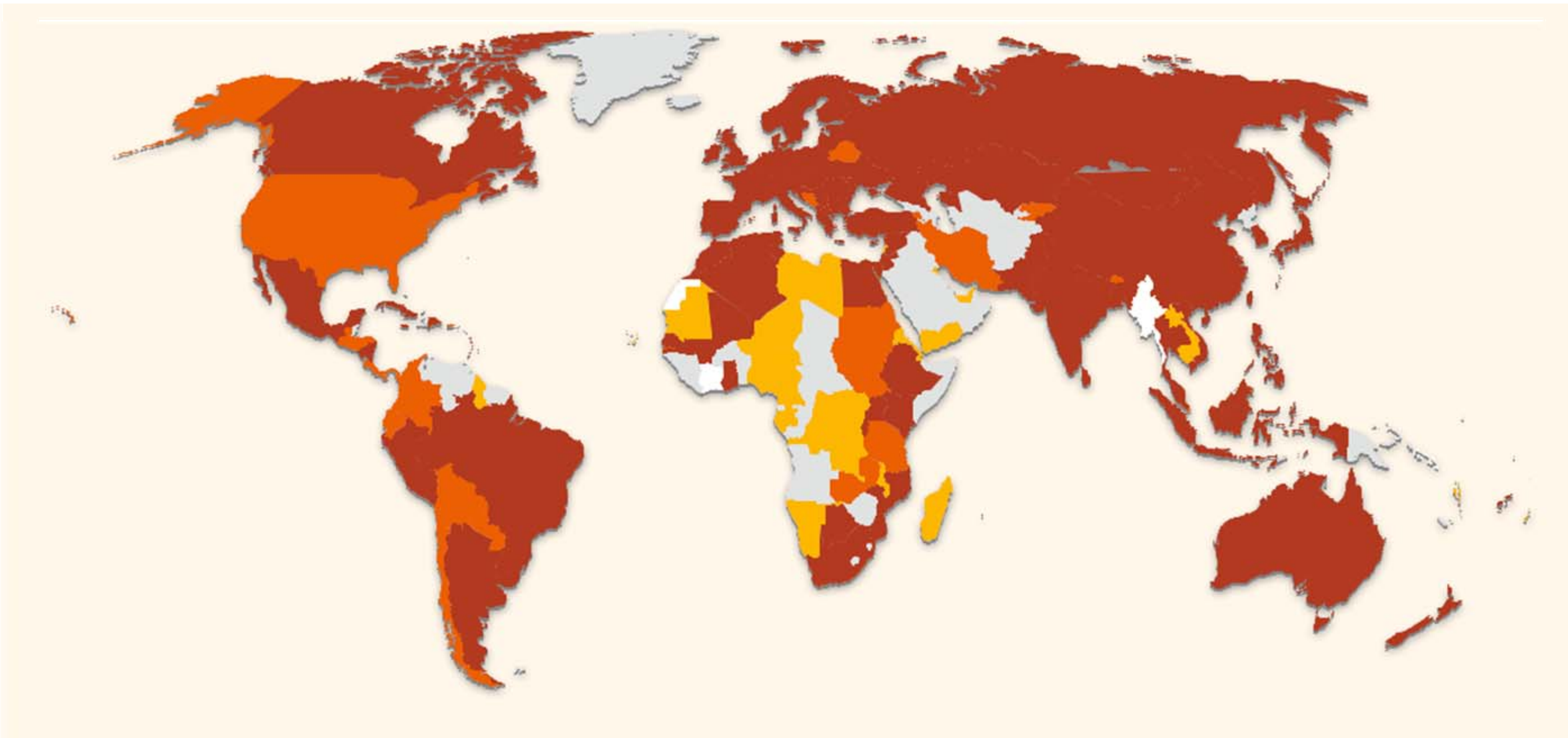
RE-specific policies and RE targets (2011)



- Countries with AT LEAST ONE National RE Policy and ONE RE Target
- Countries with AT LEAST ONE National RE Policy
- Countries with AT LEAST ONE National RE Target
- Countries without RE Policy Mechanisms and RE Targets
- No Data

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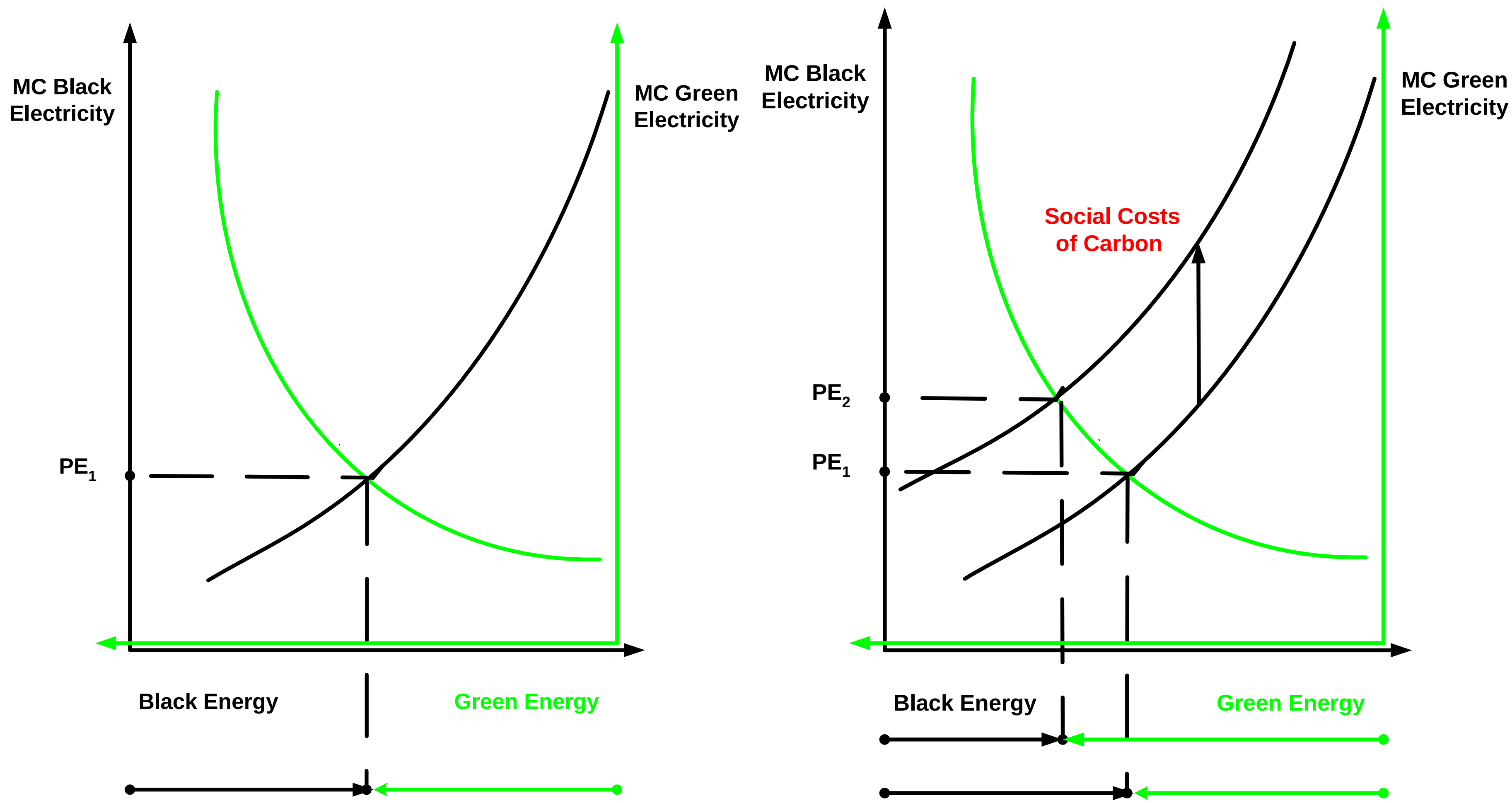
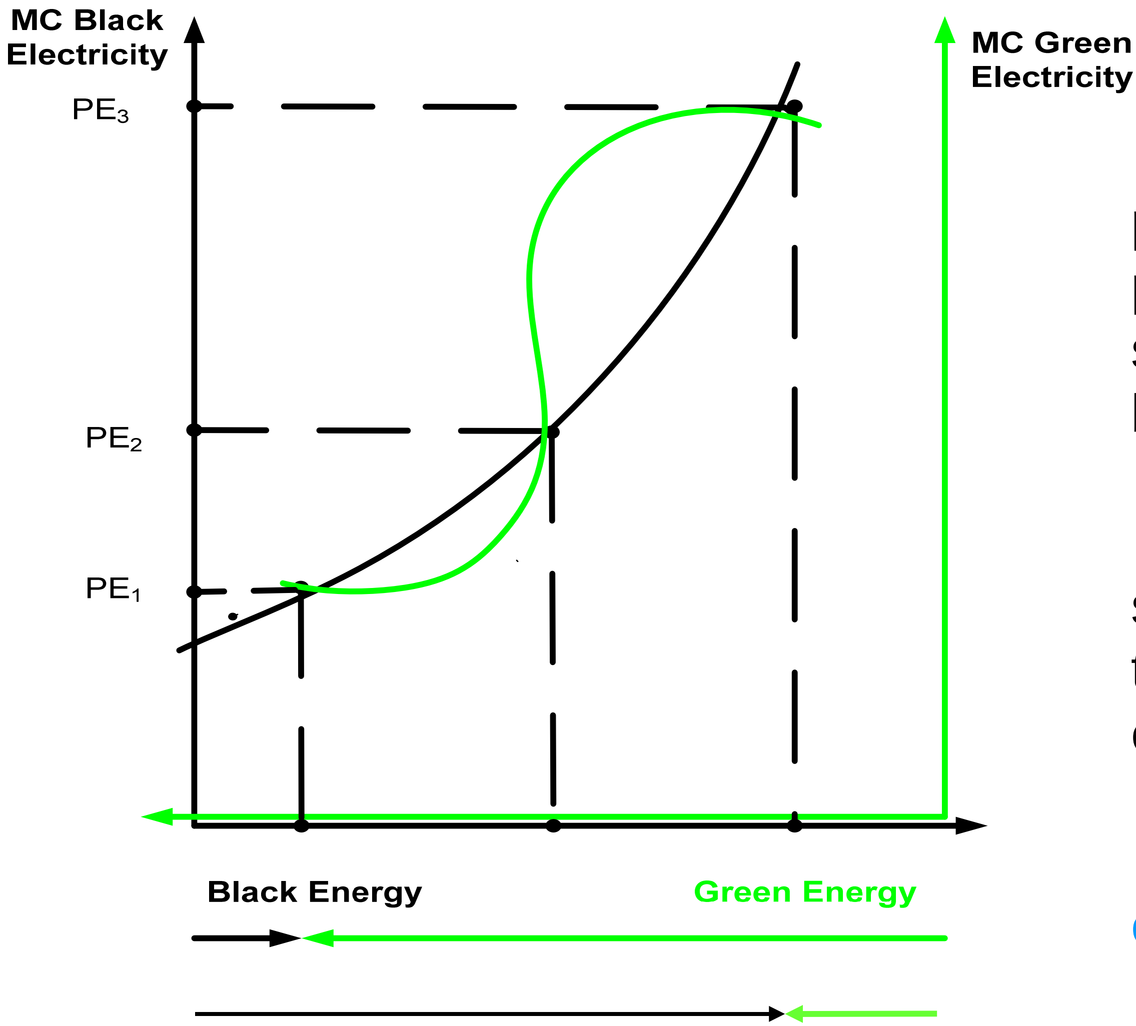
How the main stream perceives renewable energy policy



Edenhofer et al., Potsdam Institute for Climate Impact Research, Research Domain "Sustainable Solutions", 2007

A more realistic approach



- Several stable equilibrium points (PE3 and PE1) are possible if the supply curves shows 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)

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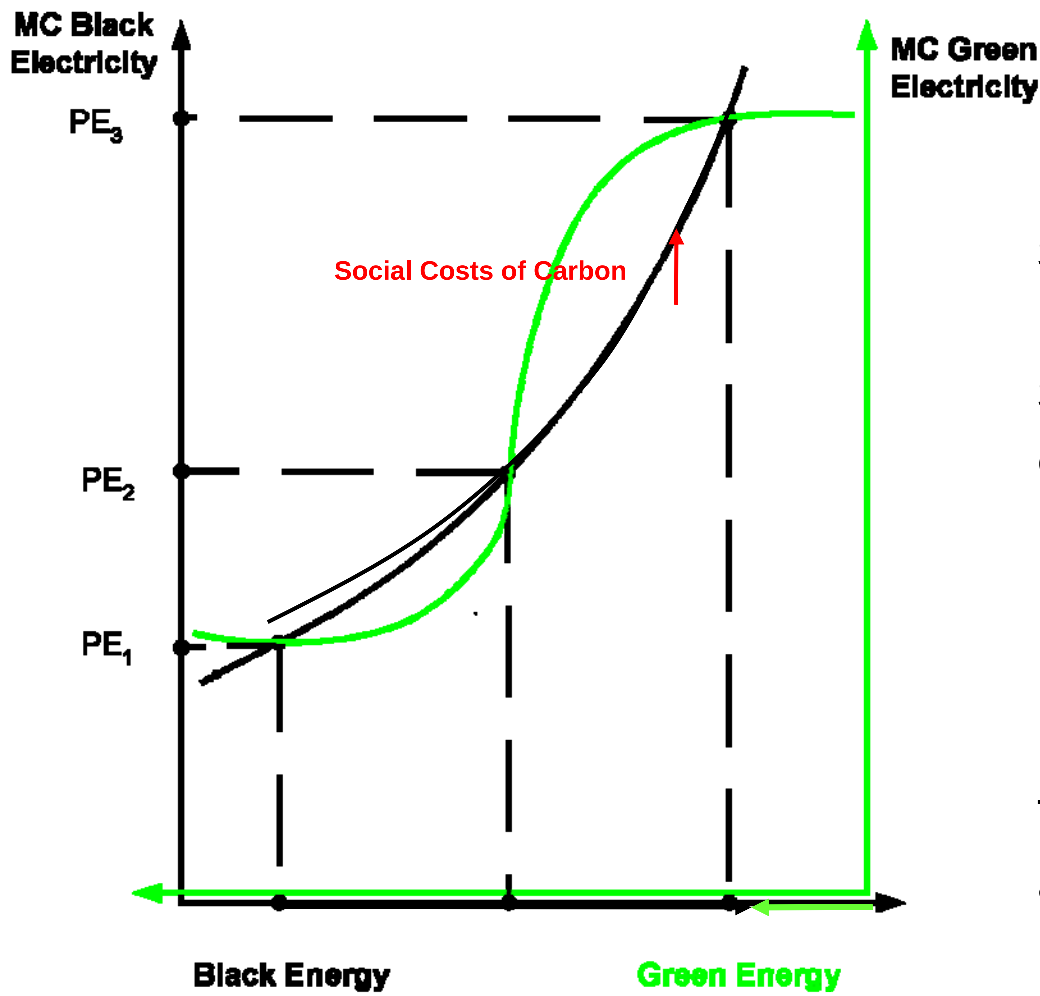
Internalizing Social Costs is Not Sufficient!

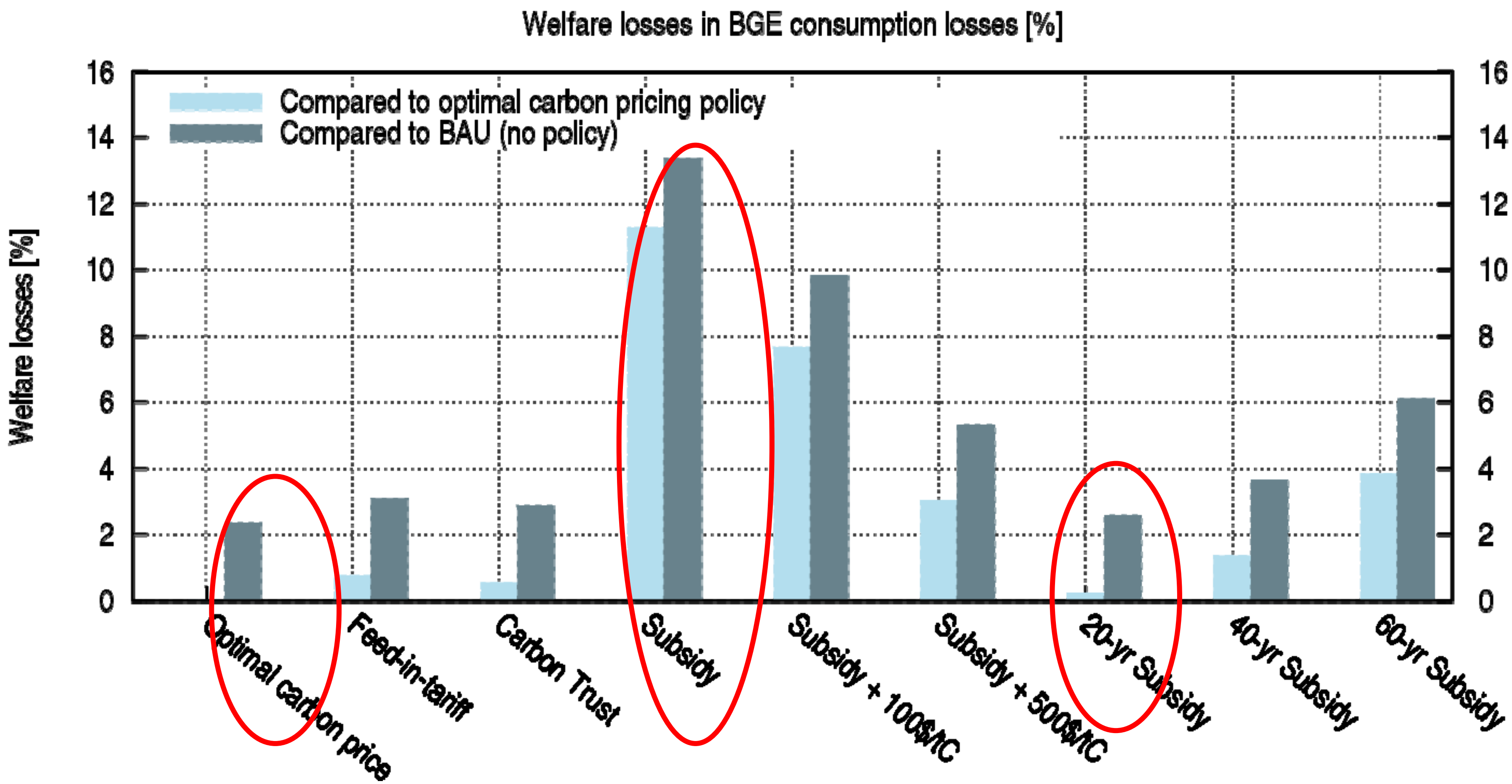


- The internalization of the social costs of energy supply (e.g. via a cap and trade system) improves the competitiveness of renewable energies

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

Edenhofer et al. (2007)

Renewable Energy Policy can be efficient



Kalkuhl und Edenhofer 2011

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Conclusion (I):
The RE pathway is not without risks

- Renewables need further technological progress which lead to decreasing costs
- The costs of integration in a existing energy system are not quantified yet.
- High deployment rates of bioenergy has opportunities but also risks, like direct and indirect land-use change
- Climate and renewable energy policies could contradict each other

Conclusion (II): Dealing with unknown unknowns

- The existing scientific knowledge is significant and can already facilitate the decision-making process.
- The report has identified the most important known unknowns (e.g. future cost and timing).
- However, the unknown unknowns require the flexibility to learn from experience and to adapt to inconvenient and convenient experiences.