



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

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Co-Chair of the IPCC Working Group III “Mitigation of Climate Change”

## Special Report on Renewable Energy Sources and Climate Change Mitigation

1. Renewable Energy and Climate Change

Introductory Chapter

2. Bioenergy

3. Direct Solar Energy

4. Geothermal Energy

5. Hydropower

6. Ocean Energy

7. Wind Energy

Technology Chapters

8. Integration of Renewable Energy into Present and Future Energy Systems

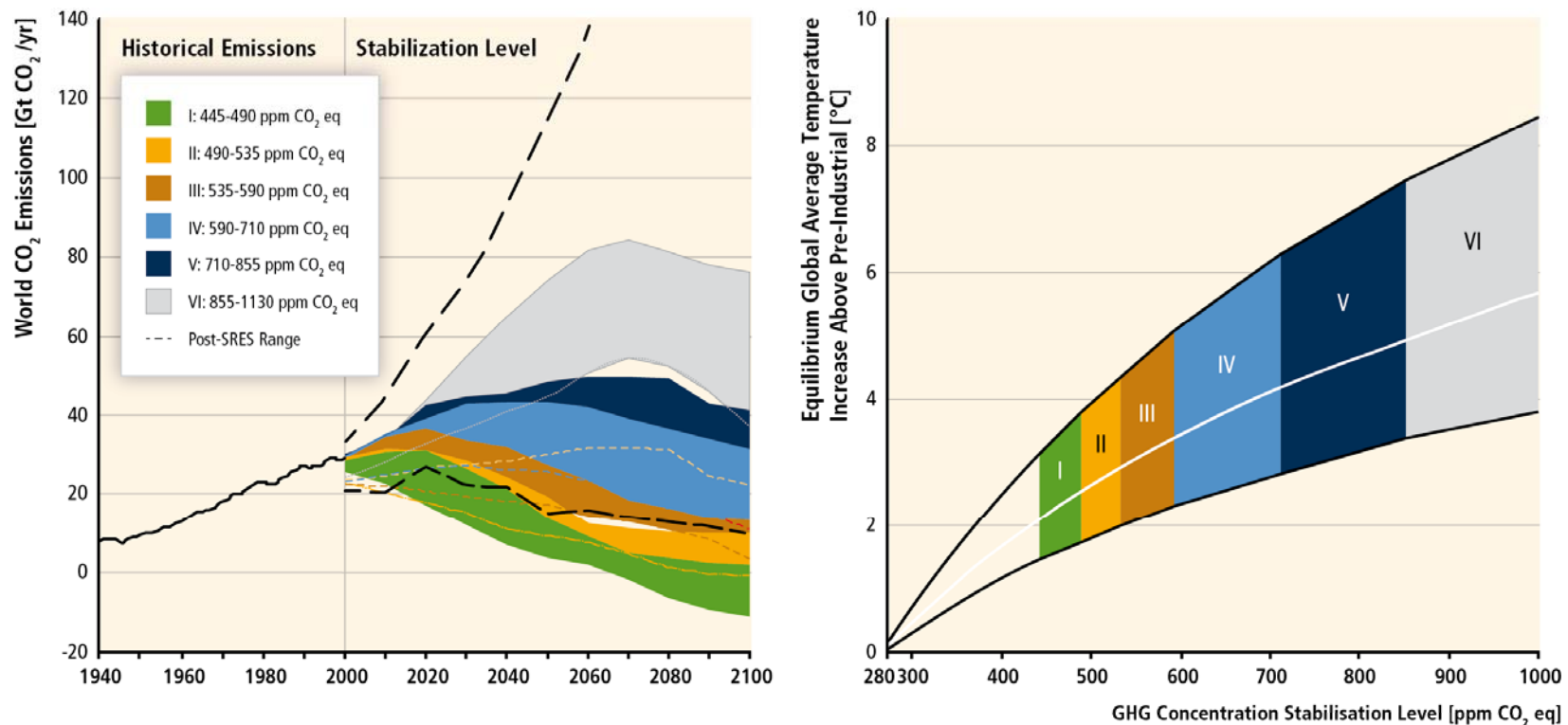
9. Renewable Energy in the Context of Sustainable Development

10. Mitigation Potential and Costs

11. Policy, Financing and Implementation

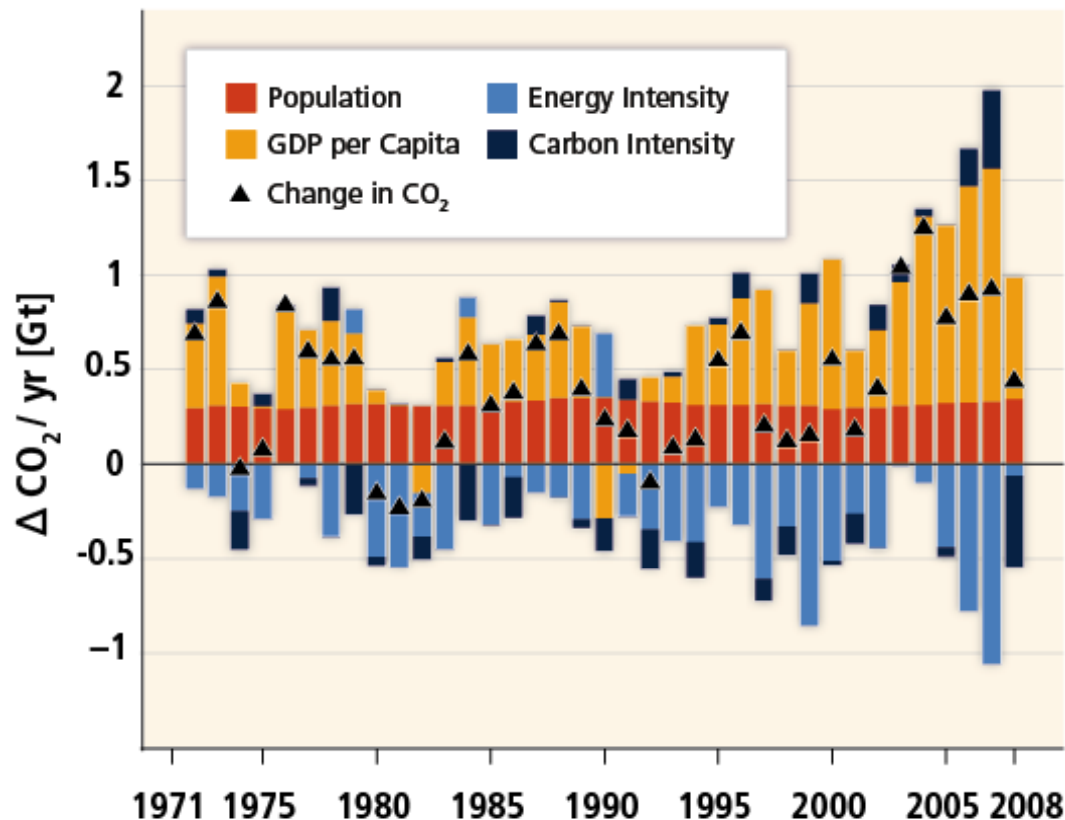
Integrative Chapters

## Demand for energy services is increasing.



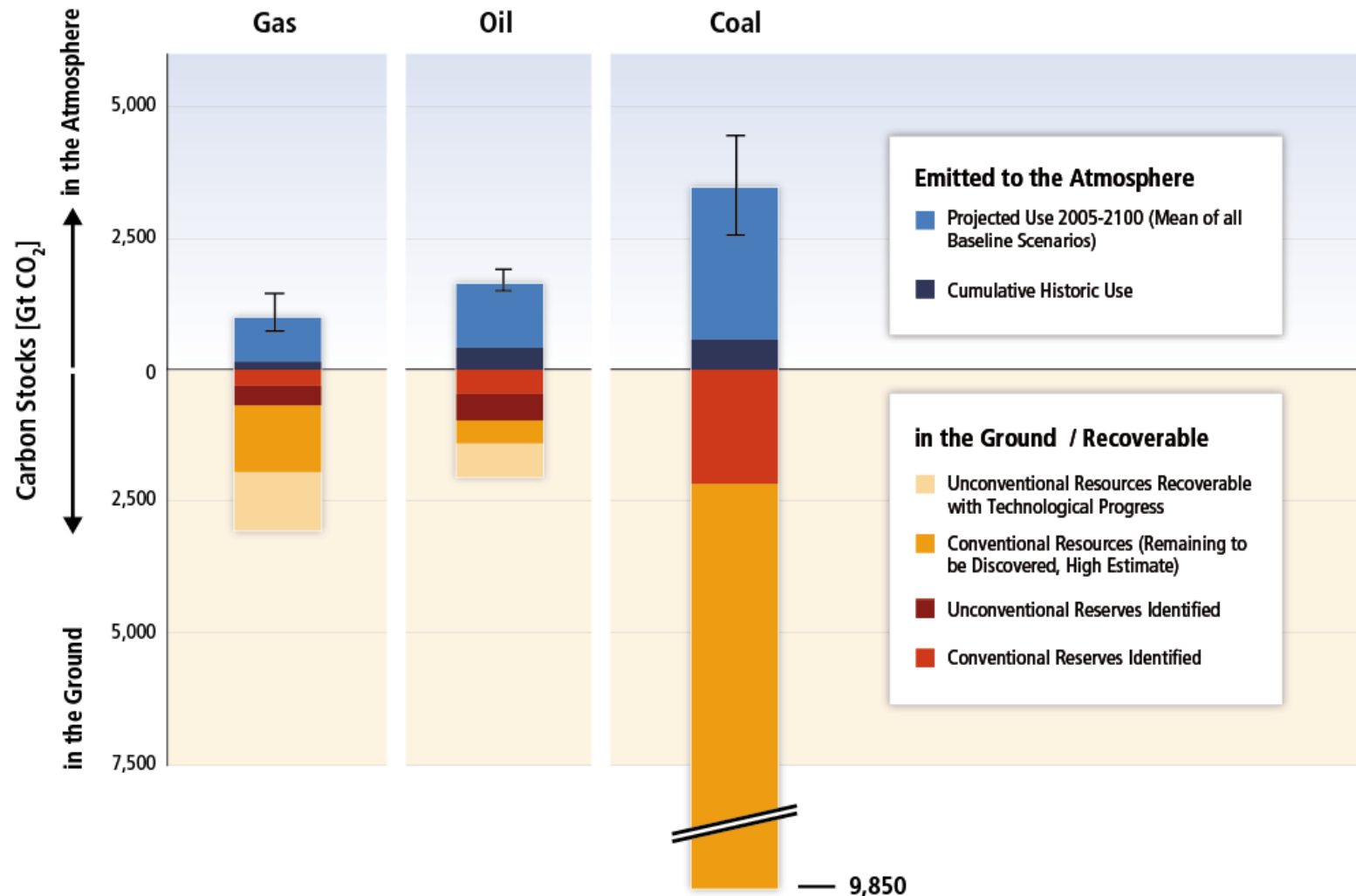
GHG emissions resulting from the provision of energy services contribute significantly to the increase in atmospheric GHG concentrations.

## Annual change in global energy-related CO<sub>2</sub> emissions

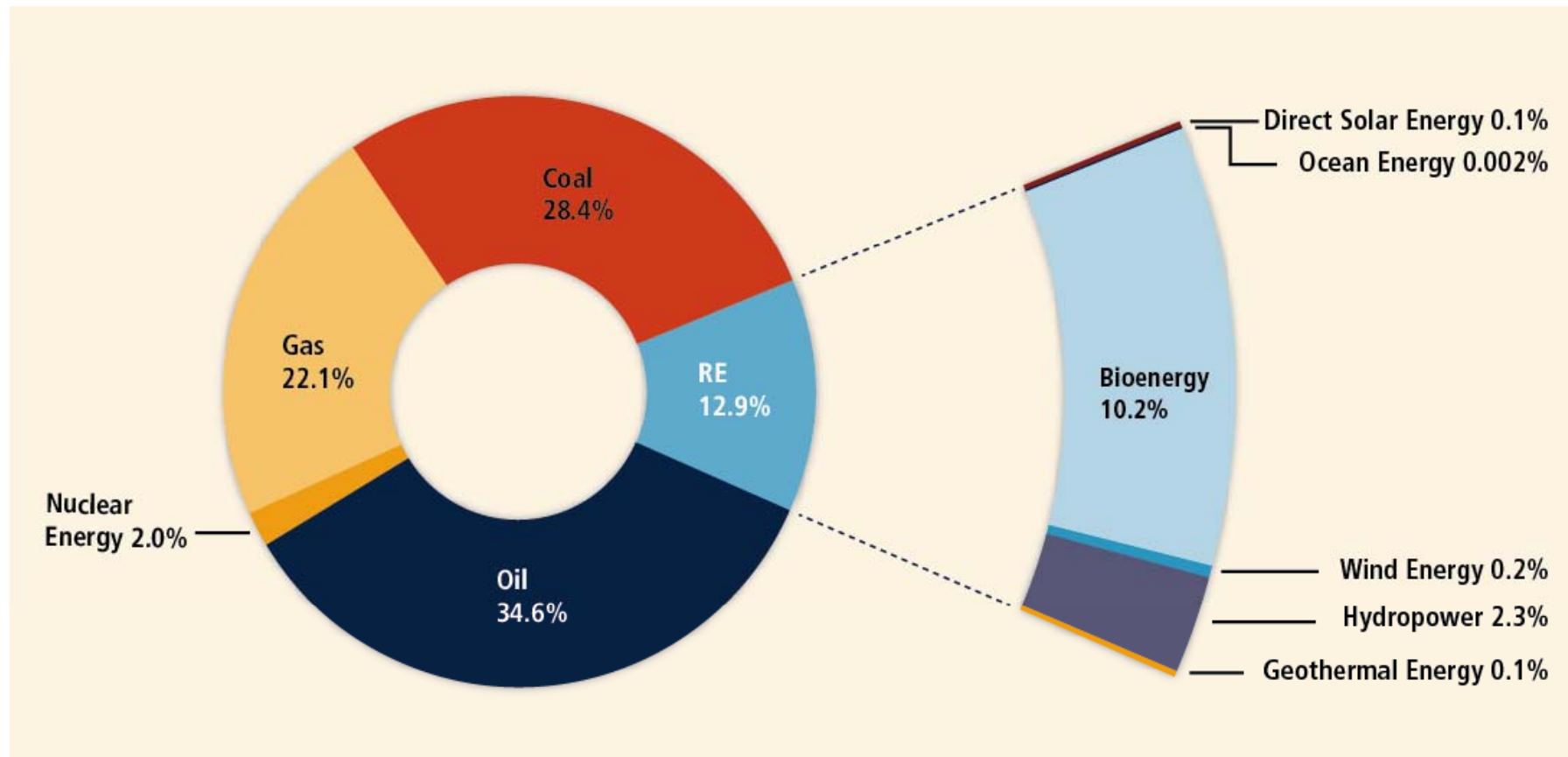


Replacing fossil fuels with RE technologies lowers carbon intensity, while improved energy efficiency can lower emissions.

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

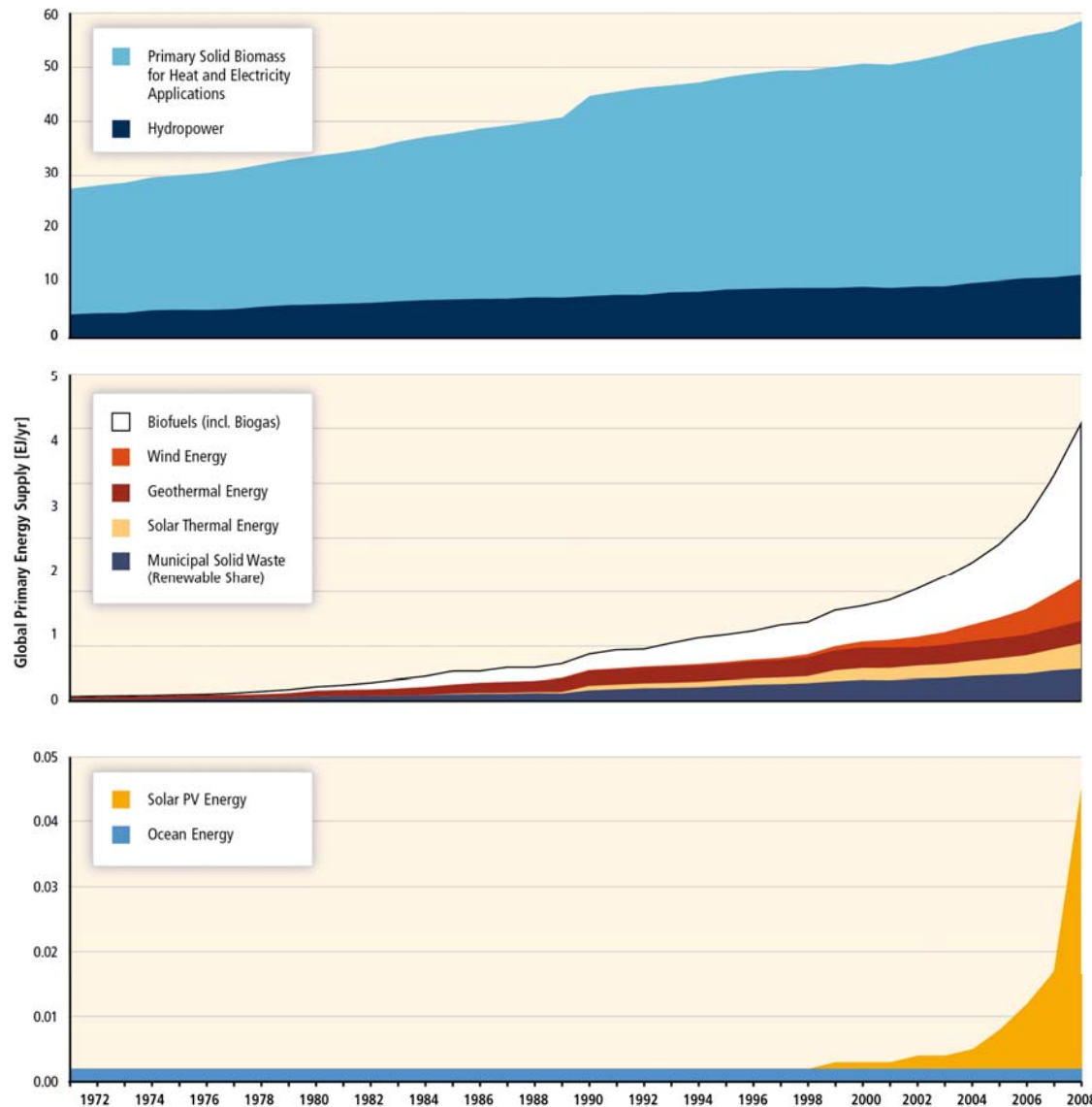


## The current global energy system is dominated by fossil fuels.



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

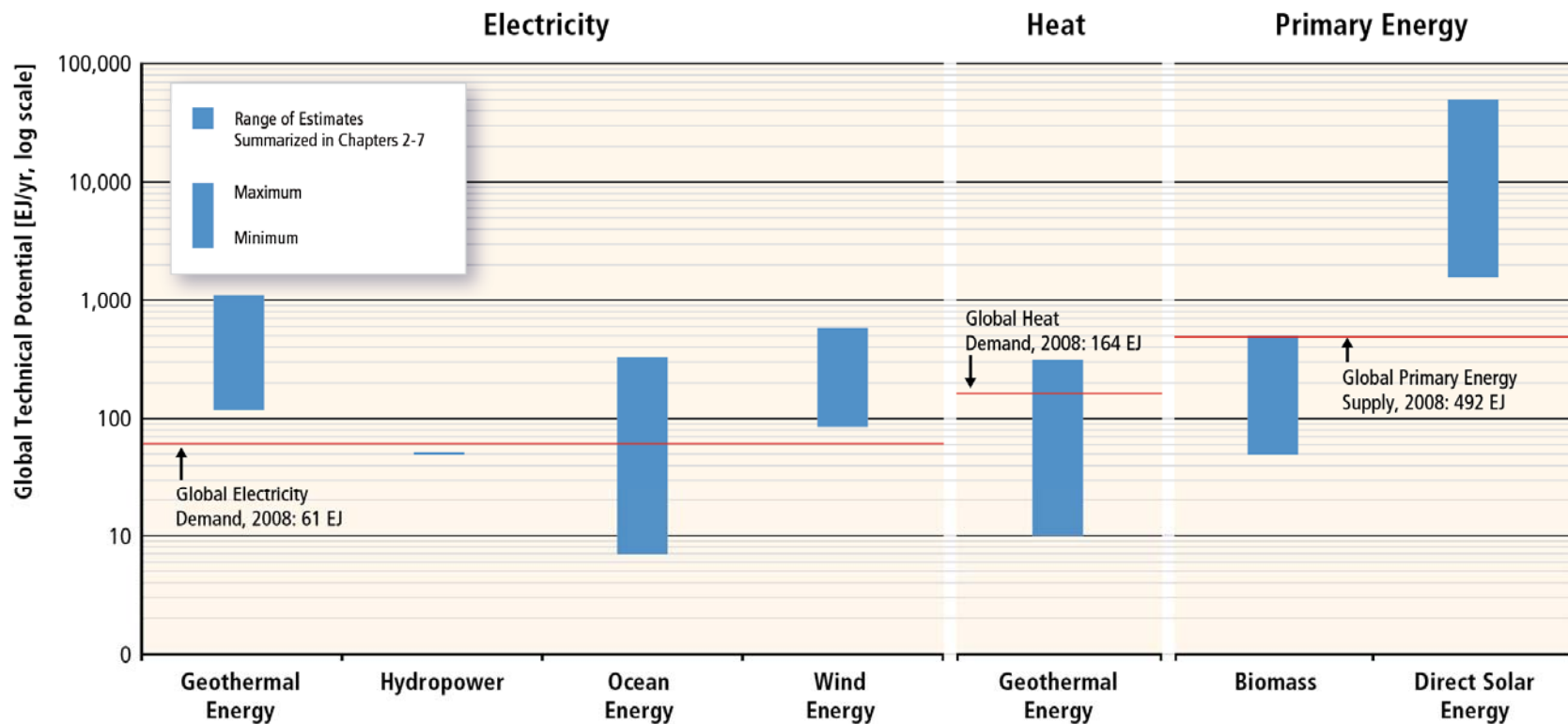
## RE growth has been increasing rapidly in recent years.



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

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

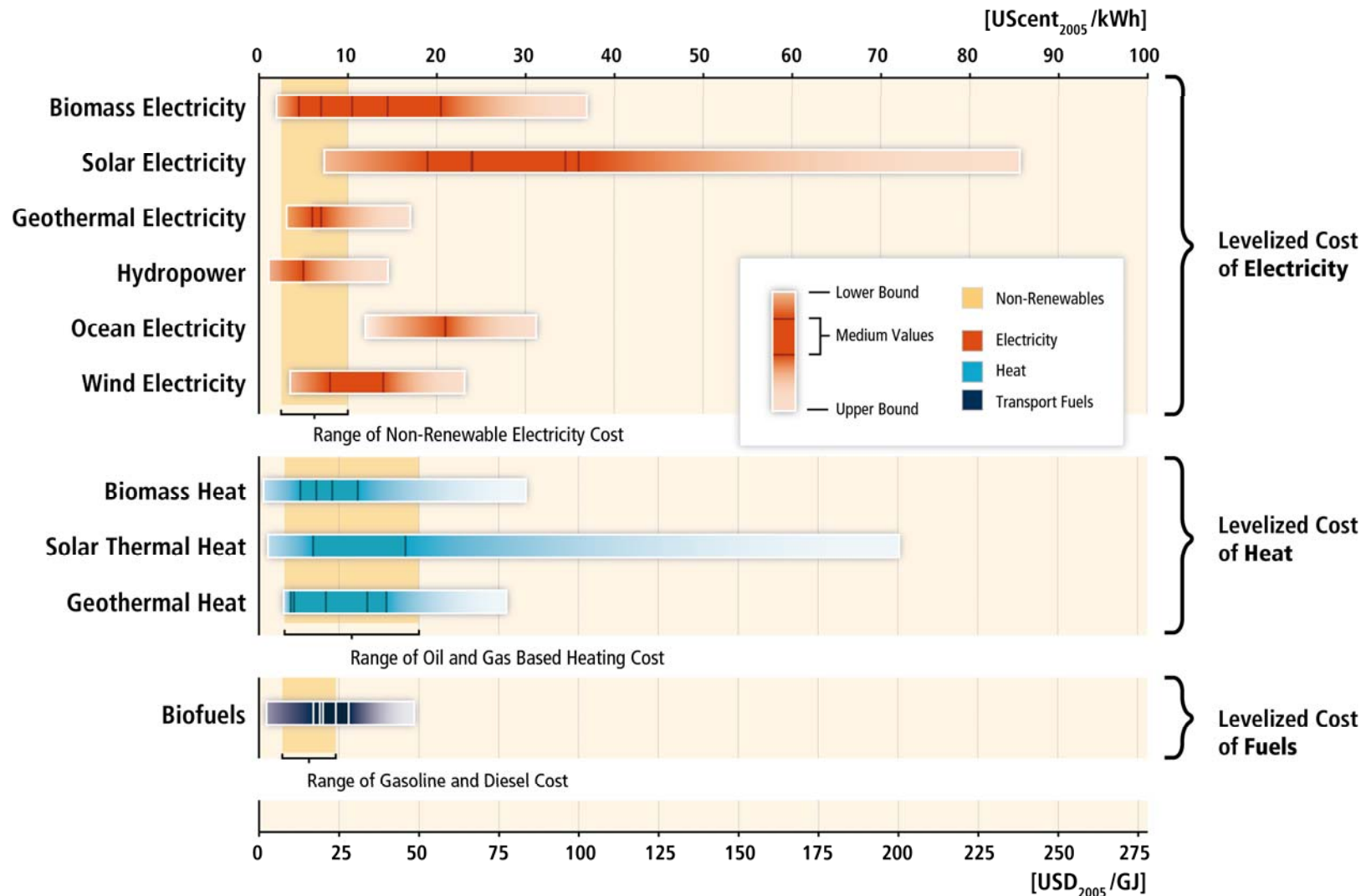
# The technical potential of renewable energy technologies to supply energy services exceeds current demands.



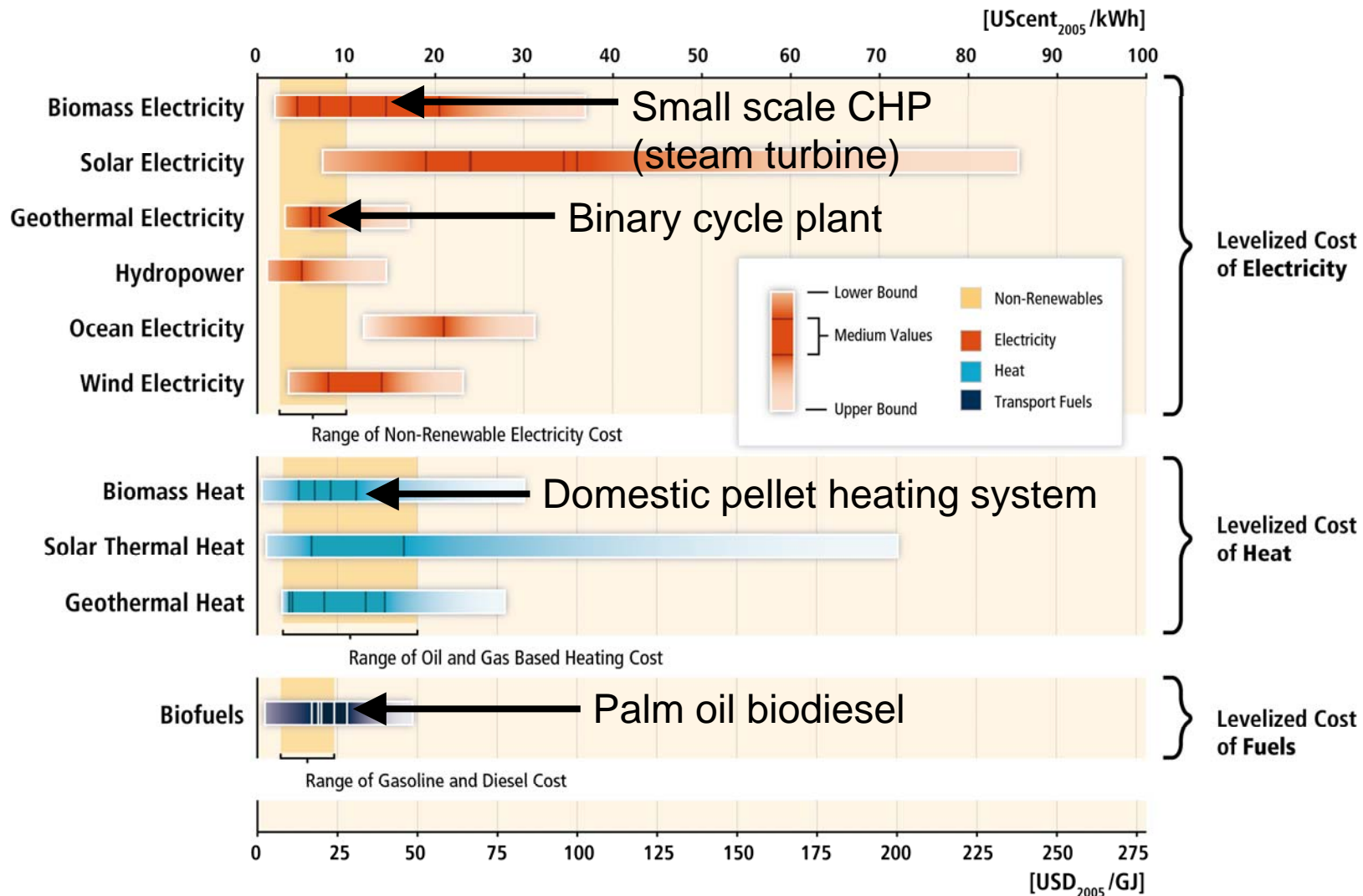
Range of Estimates of Global Technical Potentials

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

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



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



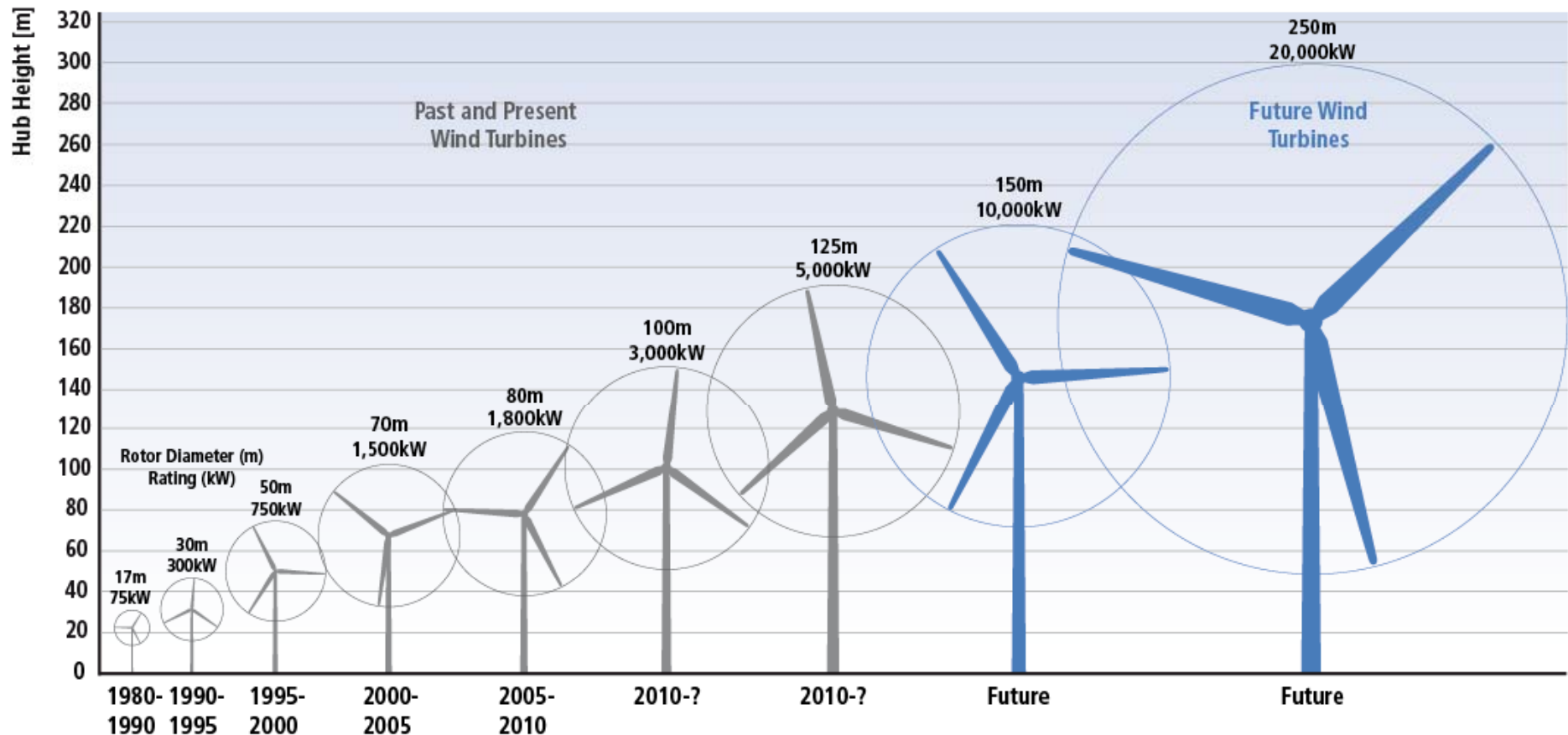
# RE costs are still higher than existing energy prices, but in various settings RE is already competitive.

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

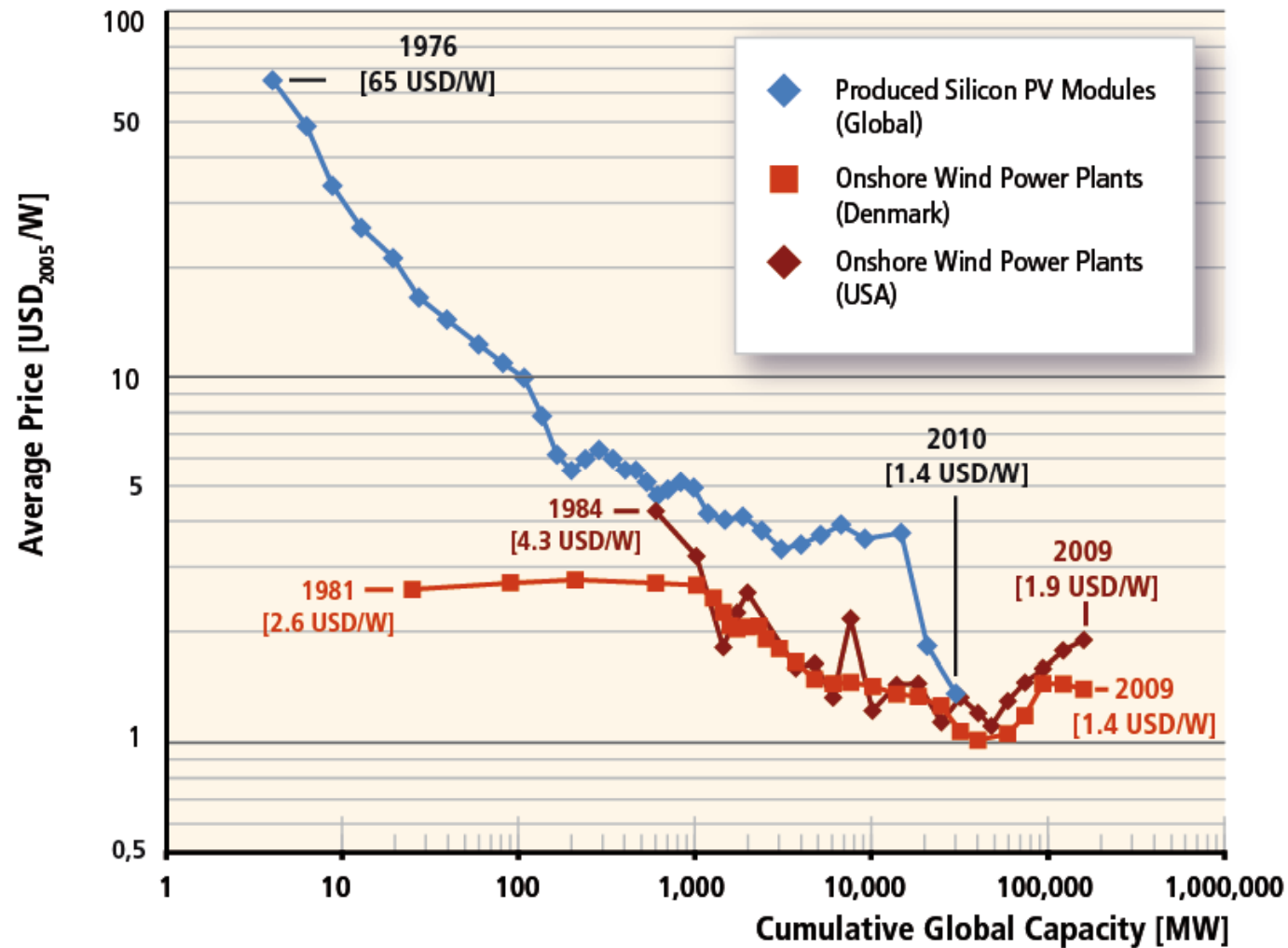
Electricity	Heat	Transport Fuels
<b>Biomass:</b> <ol style="list-style-type: none"> <li>1. Cofiring</li> <li>2. Small scale combined heat and power, CHP (Gasification internal combustion engine)</li> <li>3. Direct dedicated stoker &amp; CHP</li> <li>4. Small scale CHP (steam turbine)</li> <li>5. Small scale CHP (organic Rankine cycle)</li> </ol> <b>Solar Electricity:</b> <ol style="list-style-type: none"> <li>1. Concentrating solar power</li> <li>2. Utility-scale PV (1-axis and fixed tilt)</li> <li>3. Commercial rooftop PV</li> <li>4. Residential rooftop PV</li> </ol> <b>Geothermal Electricity:</b> <ol style="list-style-type: none"> <li>1. Condensing flash plant</li> <li>2. Binary cycle plant</li> </ol> <b>Hydropower:</b> <ol style="list-style-type: none"> <li>1. All types</li> </ol> <b>Ocean Electricity:</b> <ol style="list-style-type: none"> <li>1. Tidal barrage</li> </ol> <b>Wind Electricity:</b> <ol style="list-style-type: none"> <li>1. Onshore</li> <li>2. Offshore</li> </ol>	<b>Biomass Heat:</b> <ol style="list-style-type: none"> <li>1. Municipal solid waste based CHP</li> <li>2. Anaerobic digestion based CHP</li> <li>3. Steam turbine CHP</li> <li>4. Domestic pellet heating system</li> </ol> <b>Solar Thermal Heat:</b> <ol style="list-style-type: none"> <li>1. Domestic hot water systems in China</li> <li>2. Water and space heating</li> </ol> <b>Geothermal Heat:</b> <ol style="list-style-type: none"> <li>1. Greenhouses</li> <li>2. Uncovered aquaculture ponds</li> <li>3. District heating</li> <li>4. Geothermal heat pumps</li> <li>5. Geothermal building heating</li> </ol>	<b>Biofuels:</b> <ol style="list-style-type: none"> <li>1. Corn ethanol</li> <li>2. Soy biodiesel</li> <li>3. Wheat ethanol</li> <li>4. Sugarcane ethanol</li> <li>5. Palm oil biodiesel</li> </ol>

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.



**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/m<sup>2</sup>/yr (7,200 MJ/m<sup>2</sup>/yr)

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

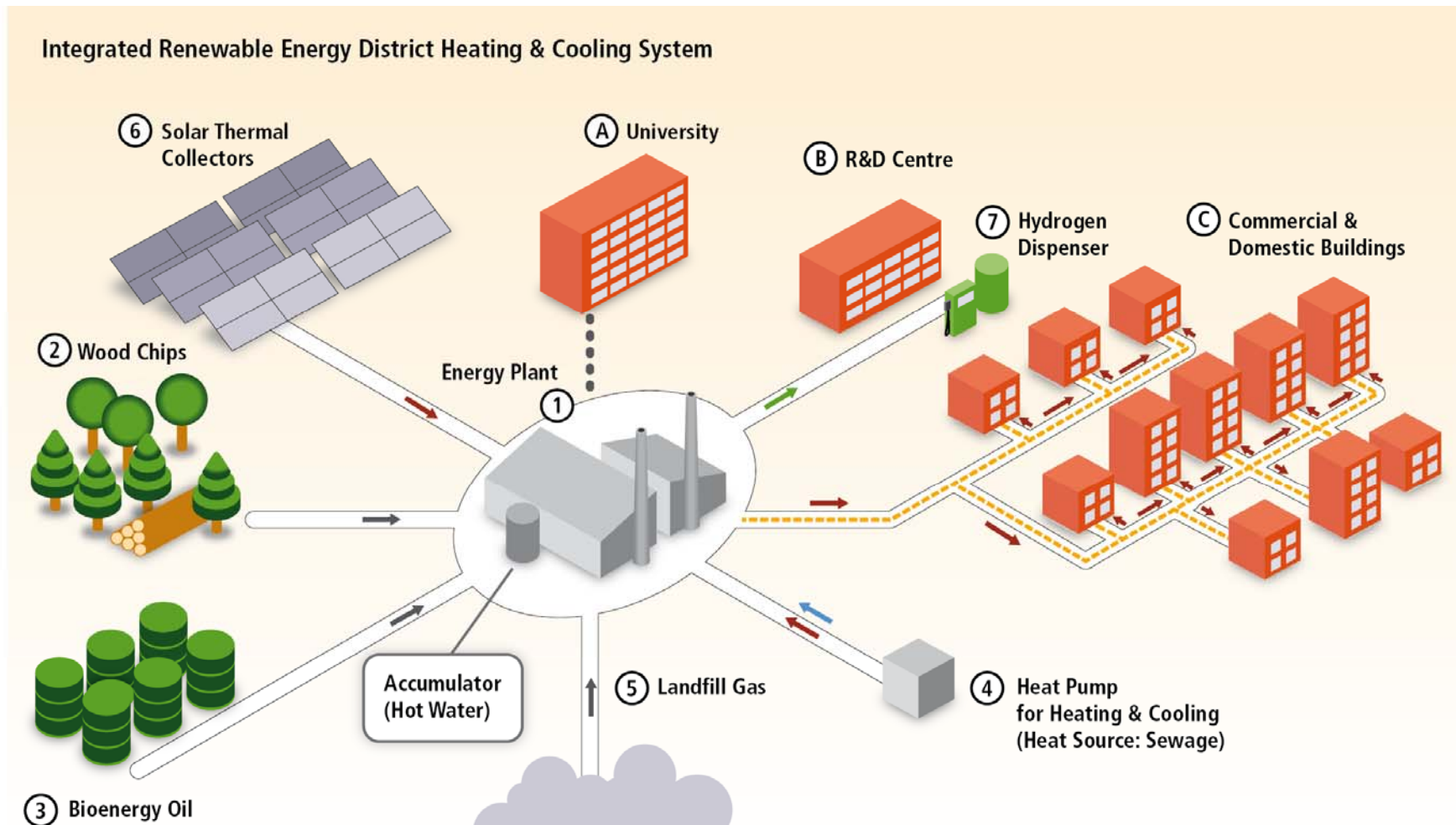
Technology		[...]	Capacity credit range
		[...]	%
Bioenergy		[...]	Similar to thermal and CHP
Direct solar energy	PV	[...]	<25–75
	CSP with thermal storage*	[...]	90
Geothermal energy		[...]	Similar to thermal
Hydropower	Run of river	[...]	0–90
	Reservoir	[...]	Similar to thermal
Ocean energy	Tidal range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

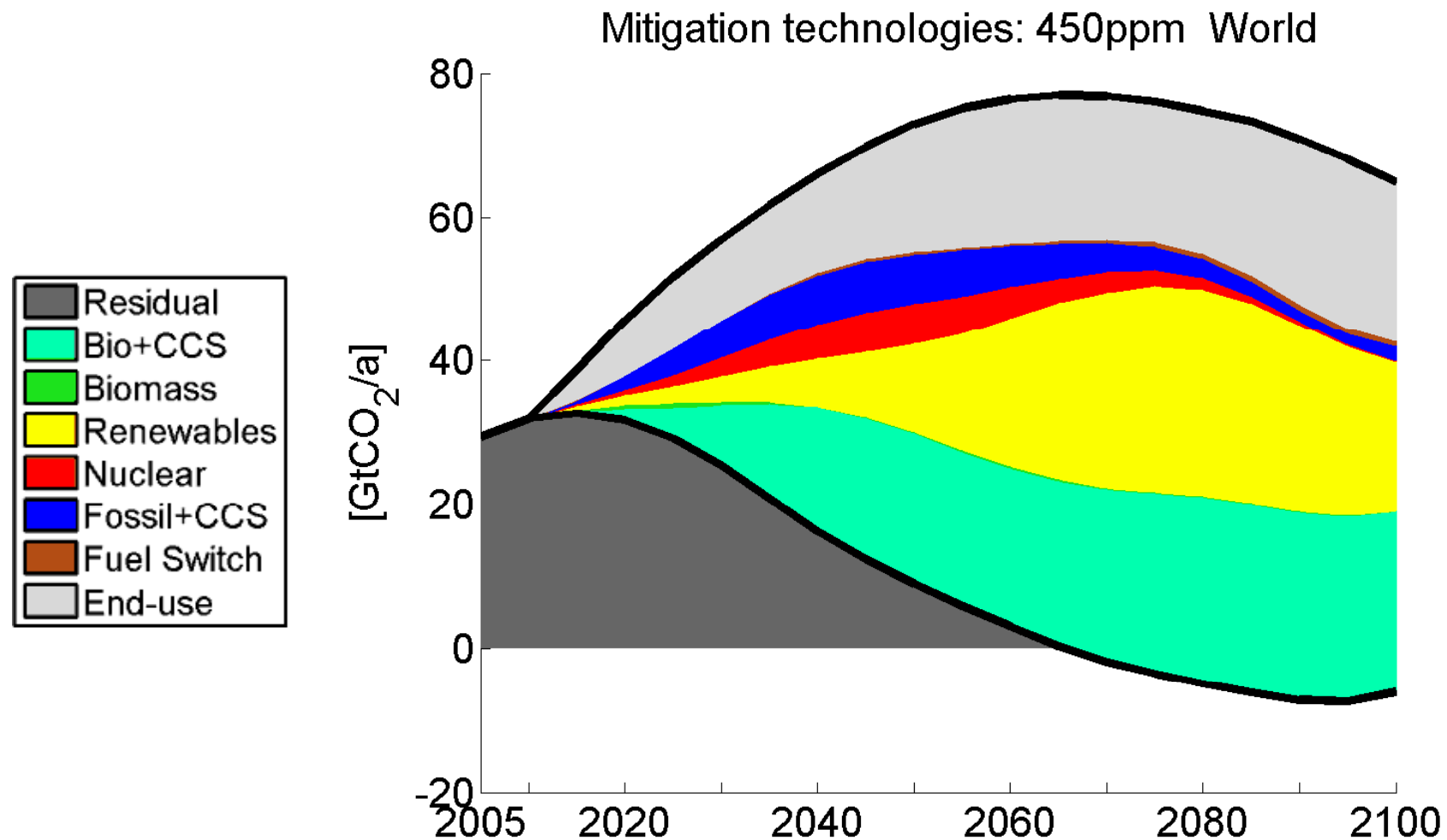
**Few, if any, fundamental technical limits exist to the integration of a majority share of RE, but advancements in several areas are needed.**

- 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



# How to decouple growth and emissions?

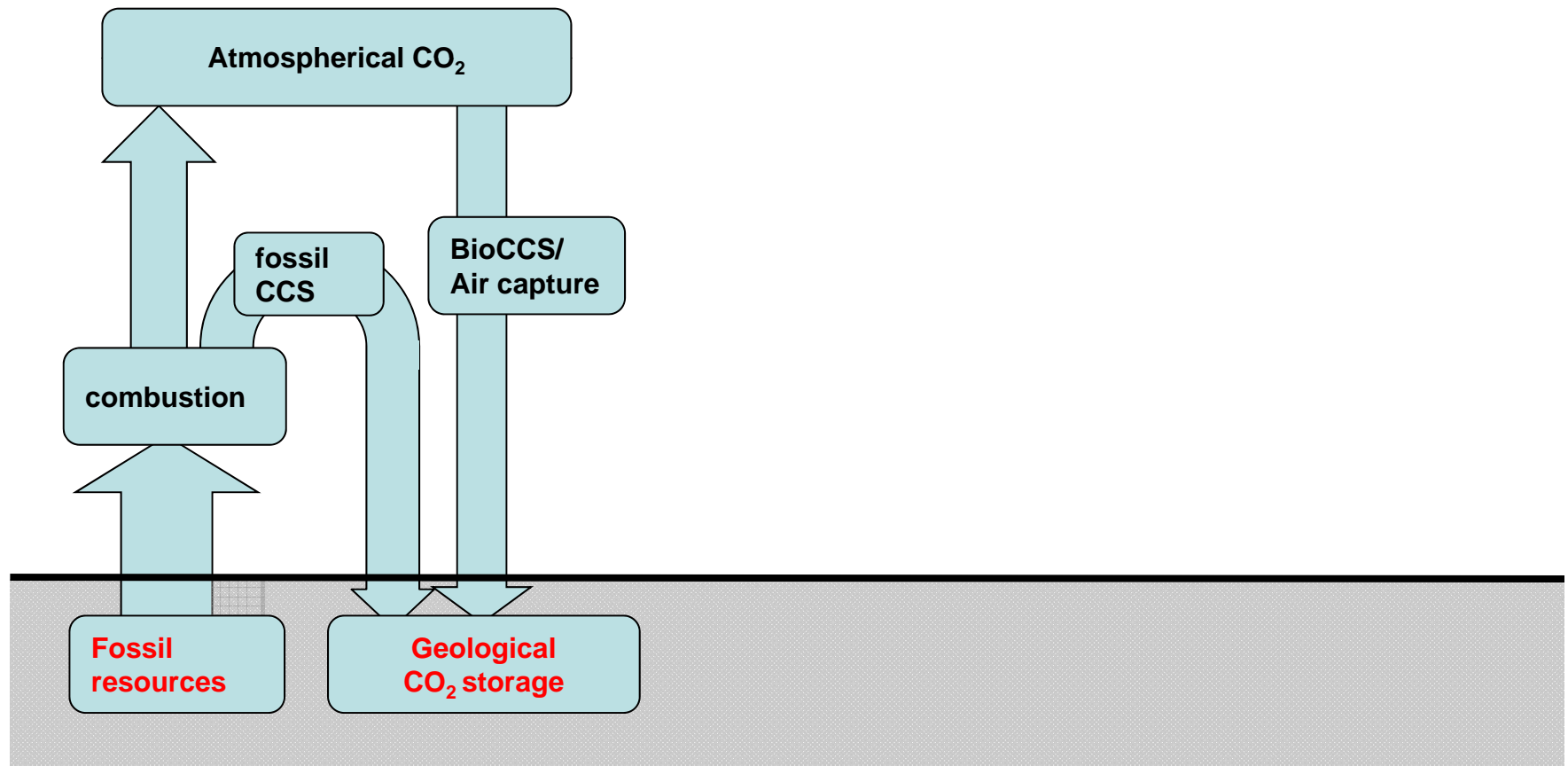


Luderer et al. (2011)

# CCX a solution for Integration? Towards the AR5

**X** = **C**ycling, **S**torage, **U**tilitization

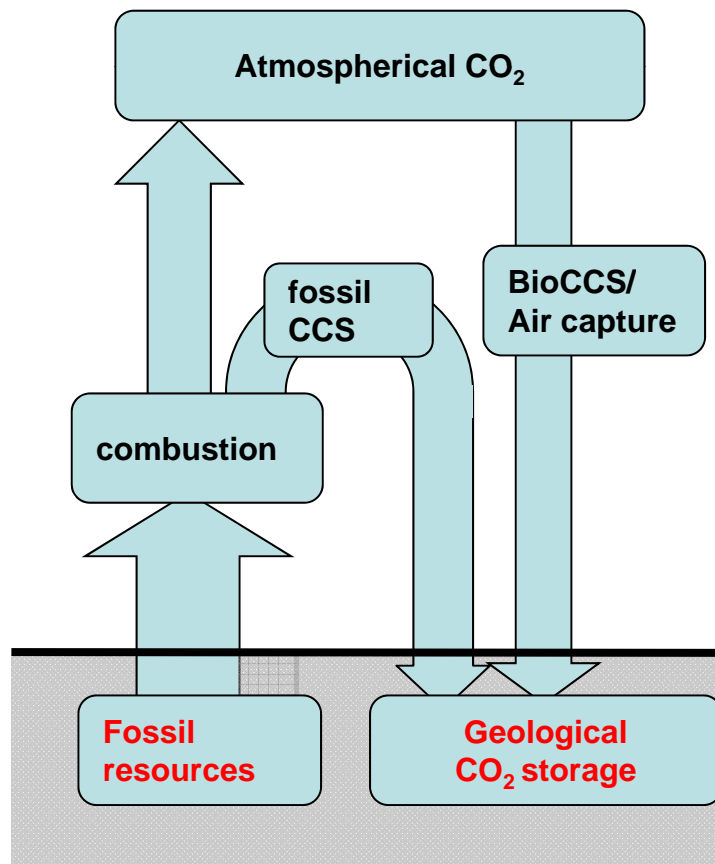
Carbon capture and storage (CCS)



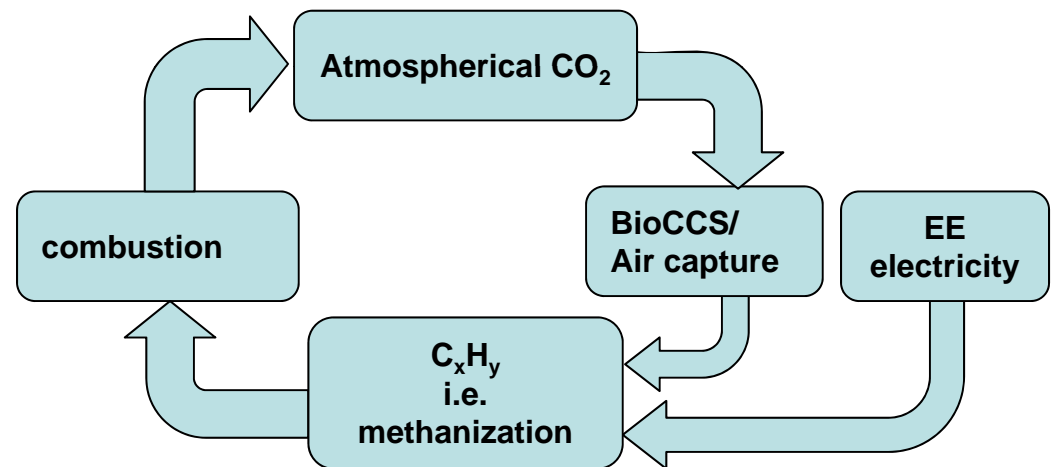
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Carbon Capture and Cycling (CCC)



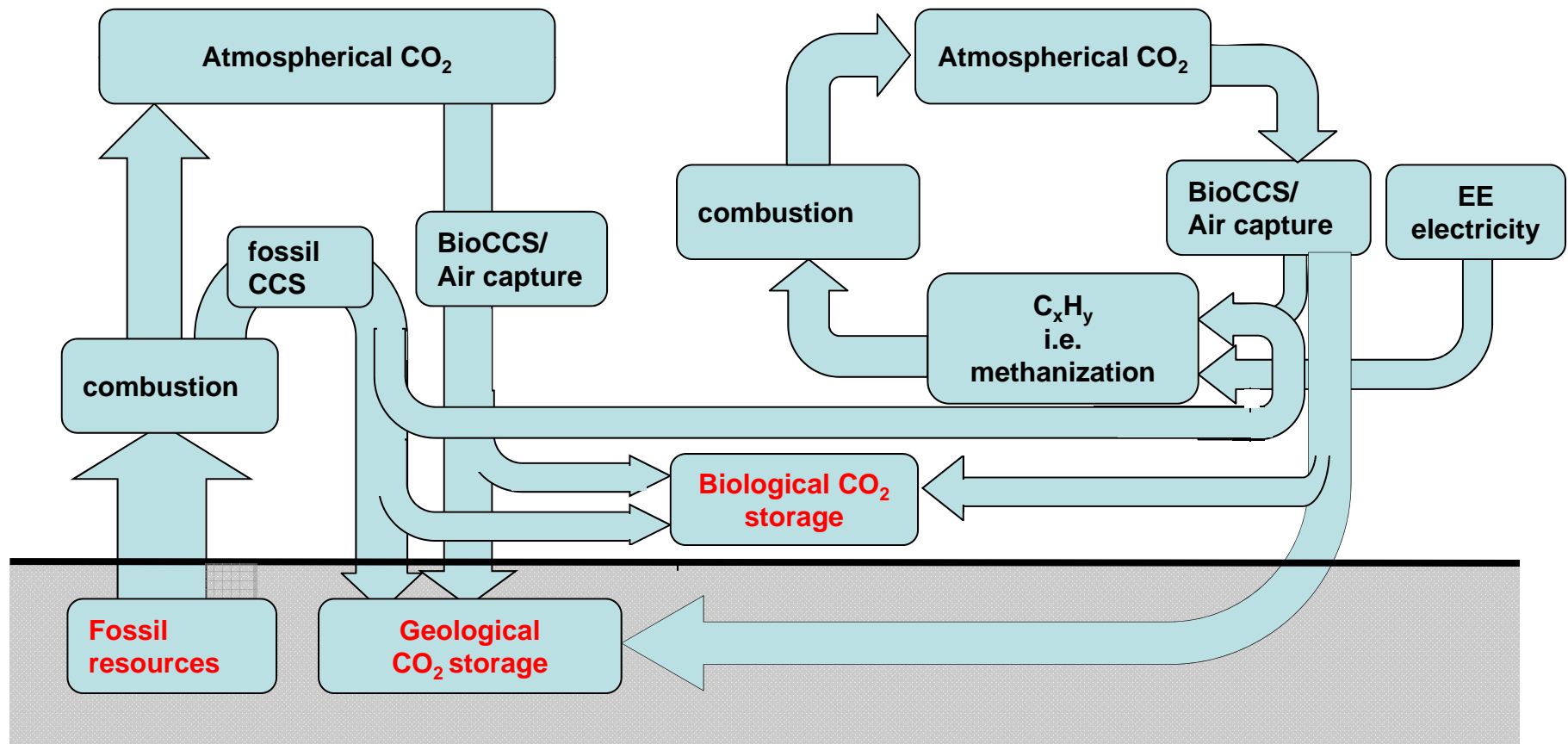
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## Carbon Capture and Use (CCU)

Carbon capture and storage (CCS)

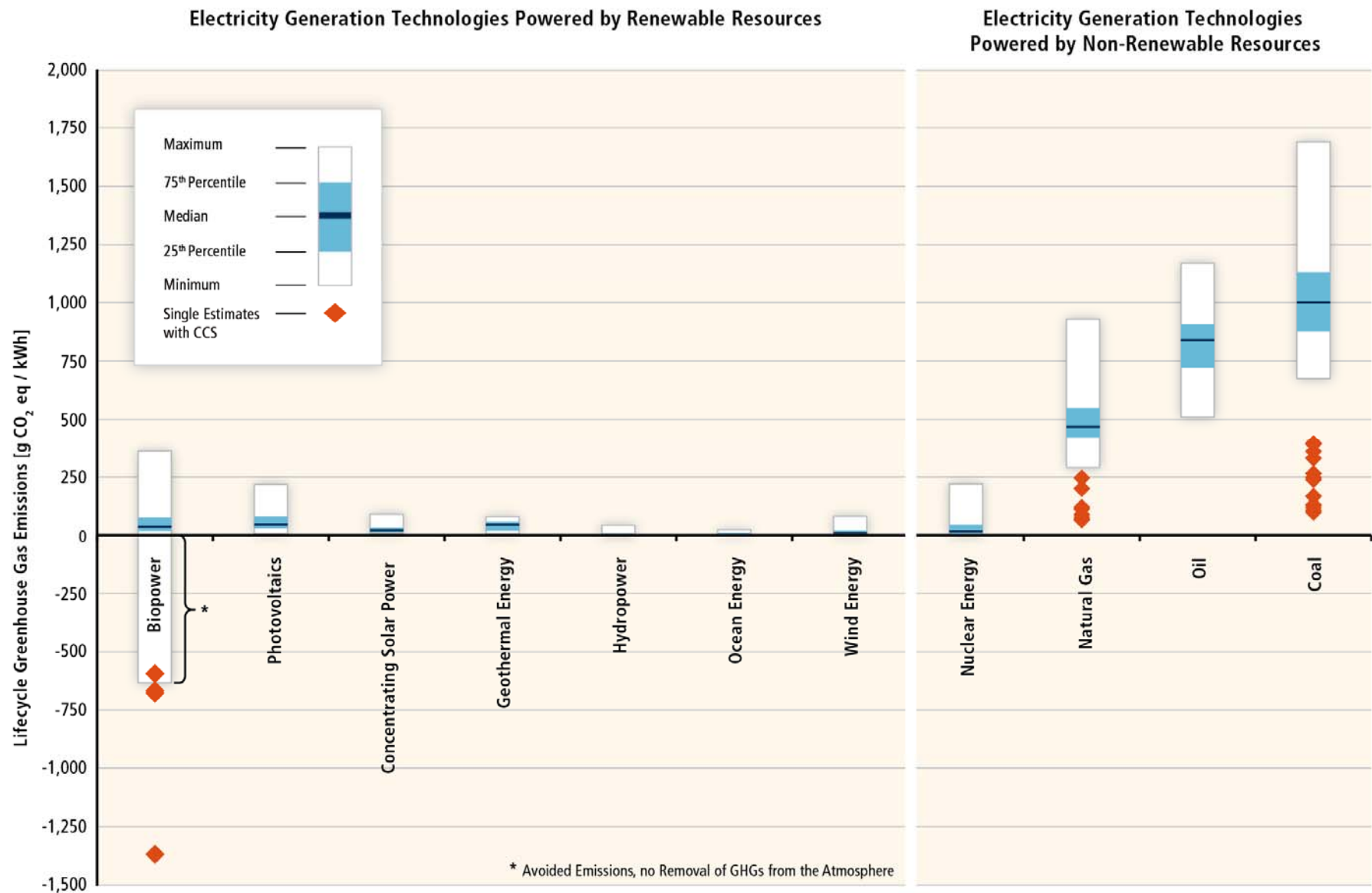
Carbon Capture and Cycling (CCC)



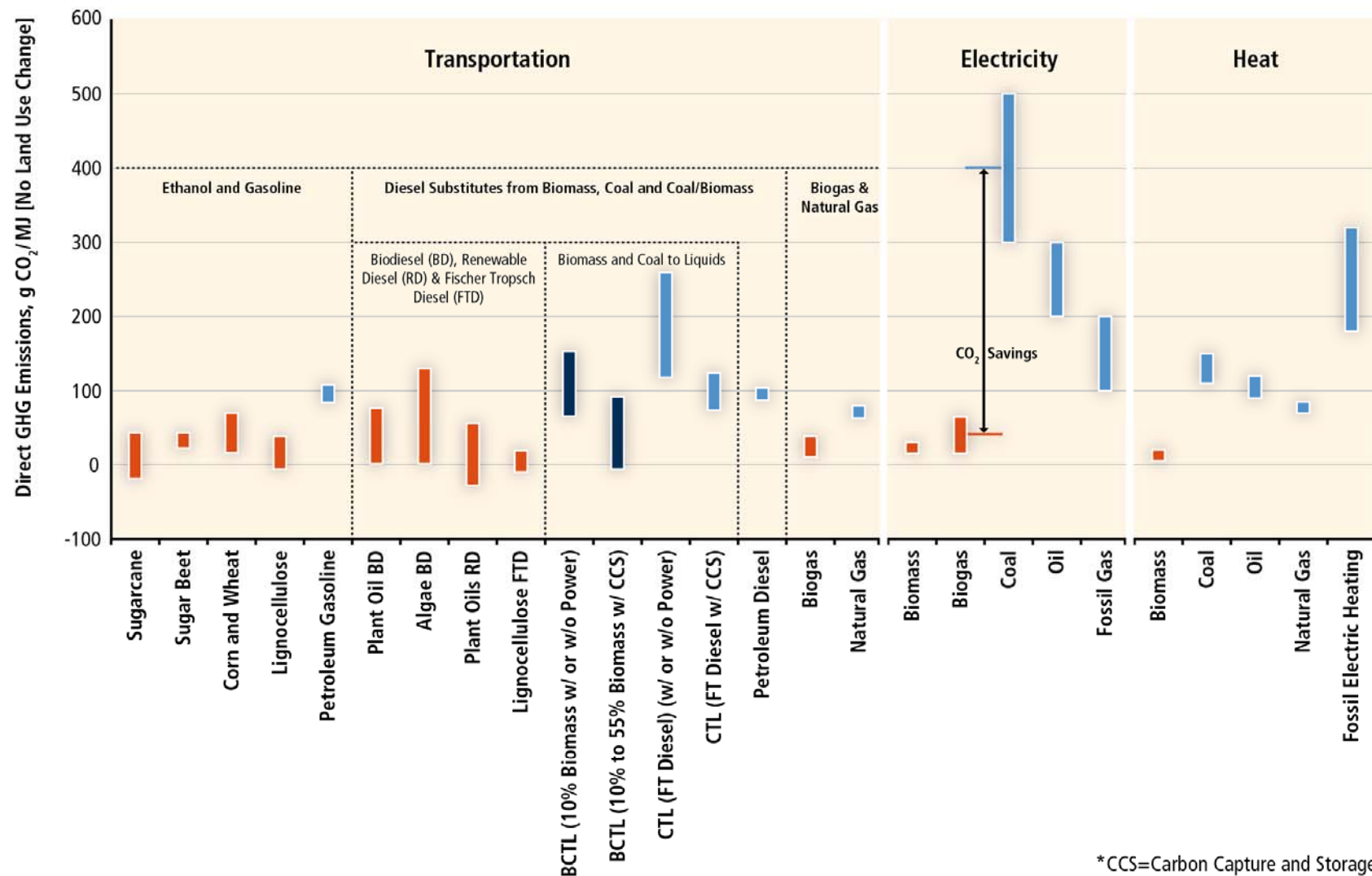
## **RE can contribute to sustainable development.**

- 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

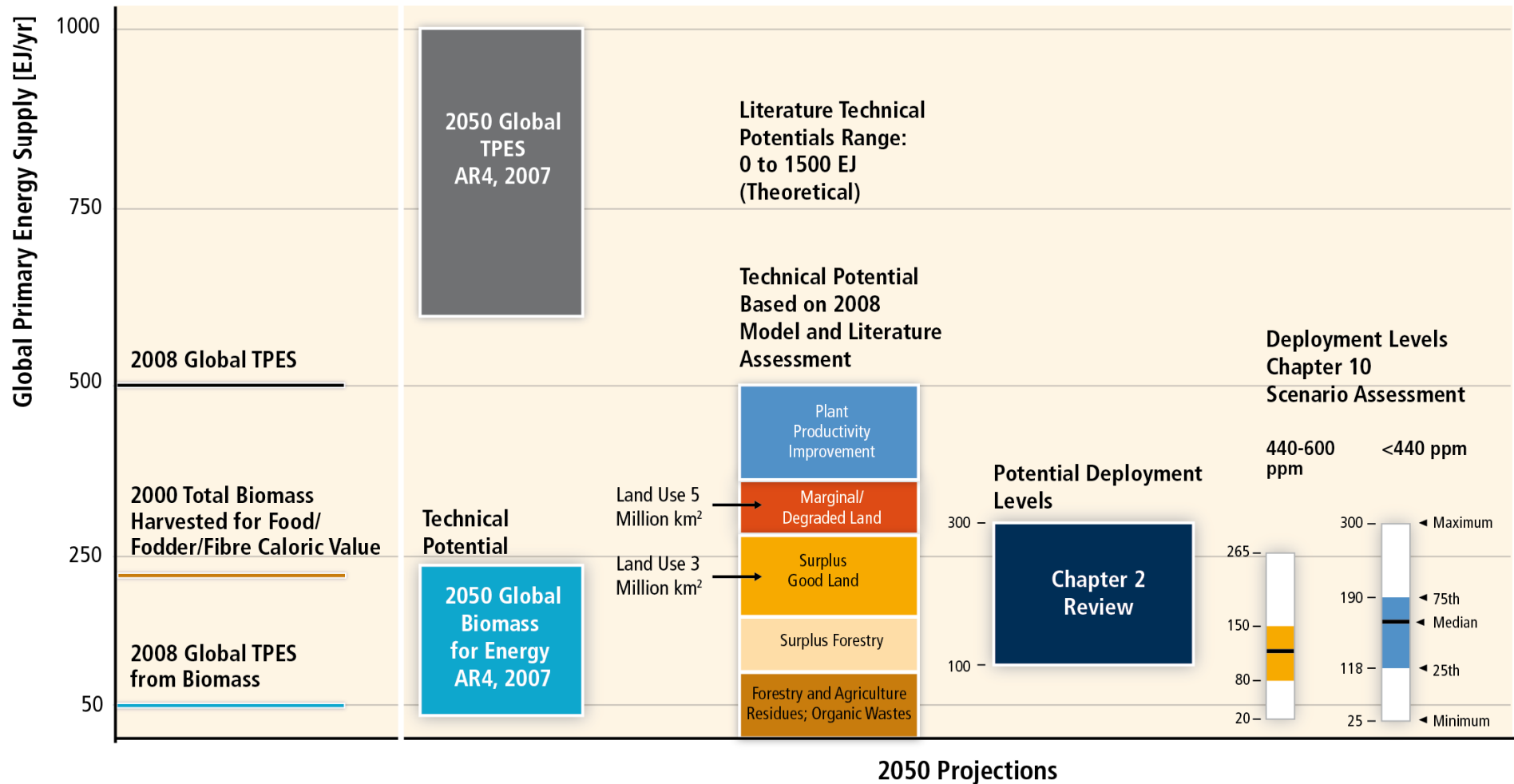
**Lifecycle GHG emissions of RE technologies are, in general, considerably lower than those of fossil fuel options.**



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



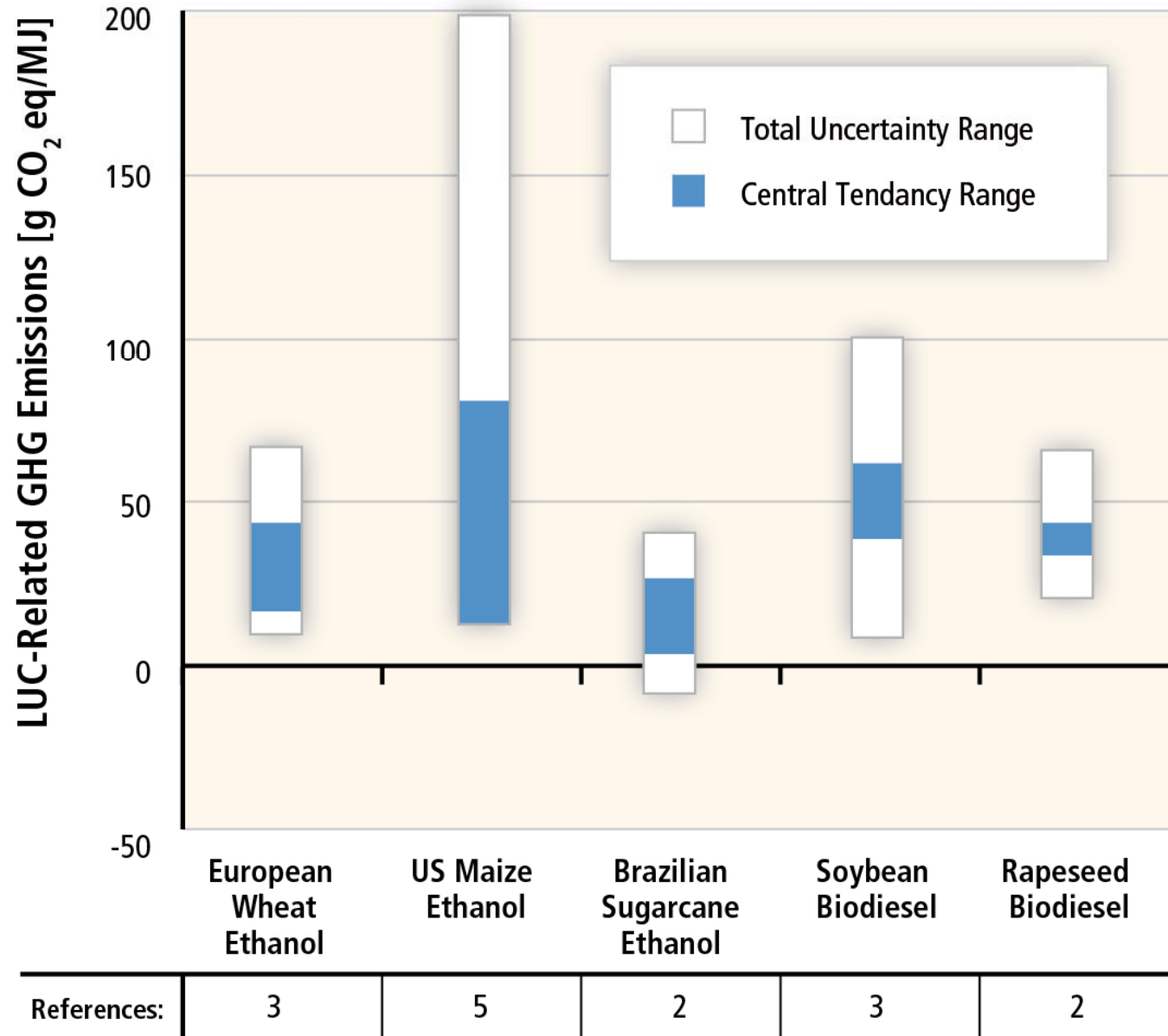
# Terrestrial biomass for energy



## Land-use change and bioenergy

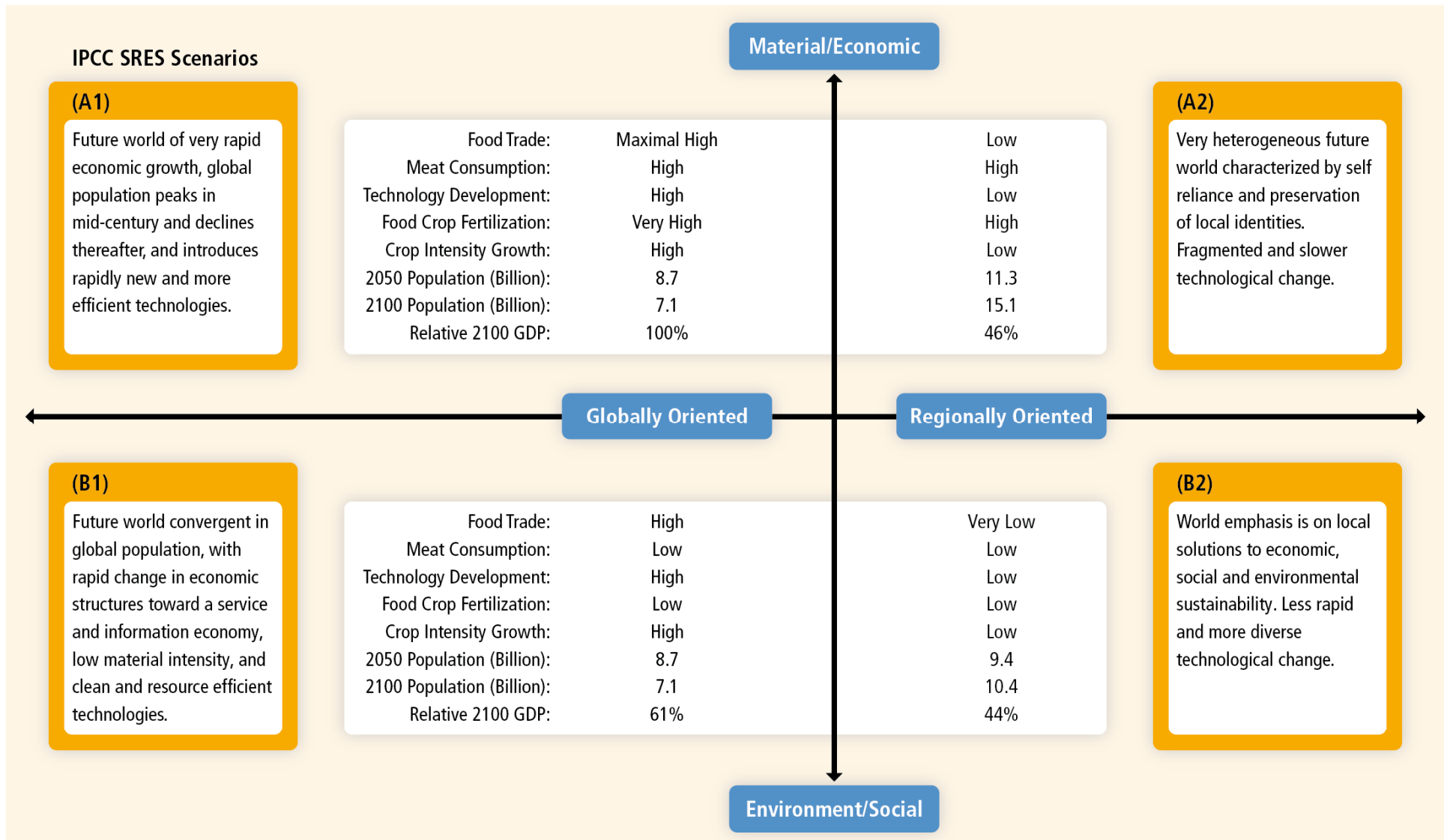
- The positive greenhouse gas balance of biofuels can be affected by direct and indirect land-use changes.
- Proper governance of land use, zoning, and choice of biomass production systems are key challenges for policy makers

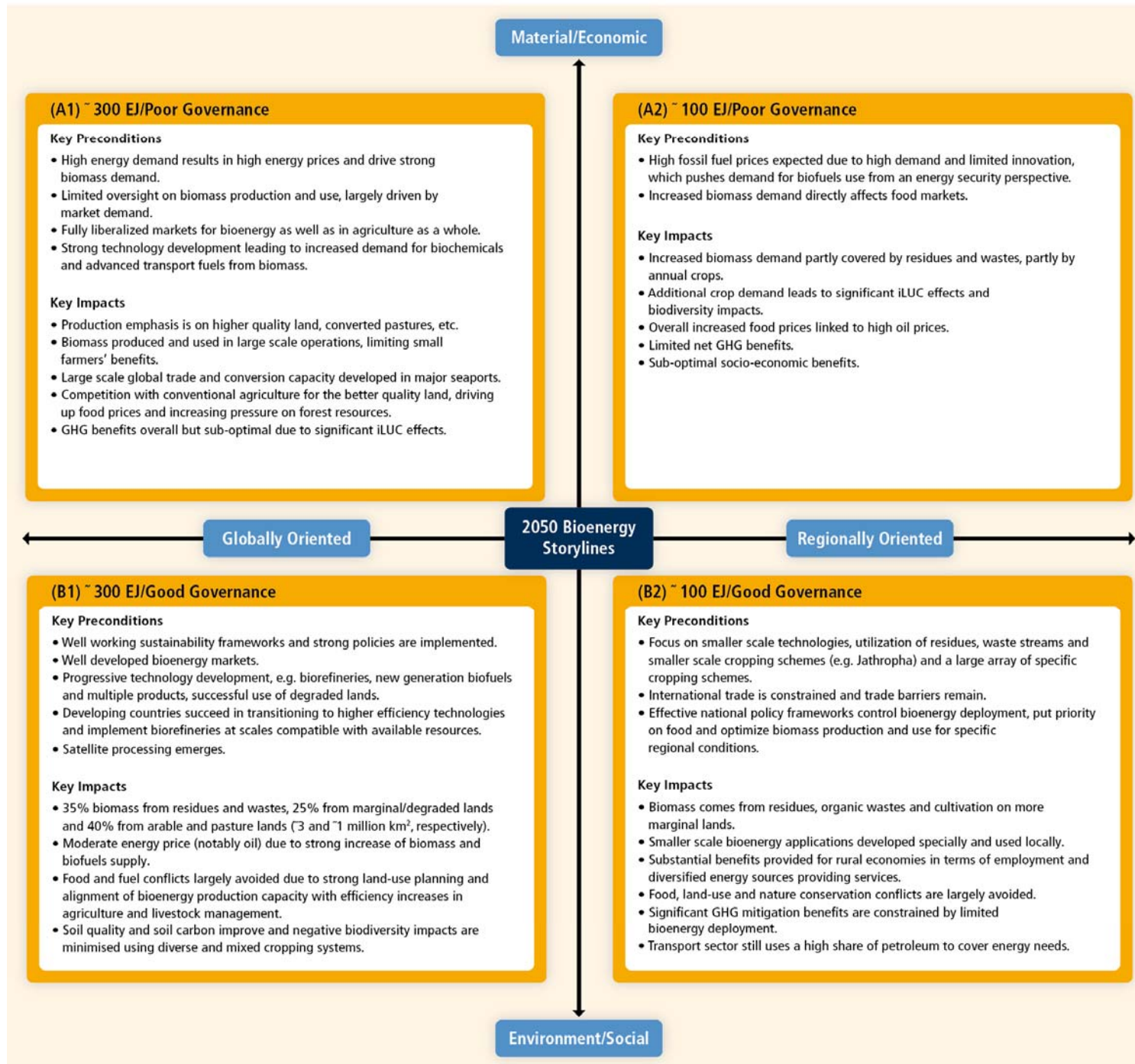
## Direct and indirect land use GHG emissions



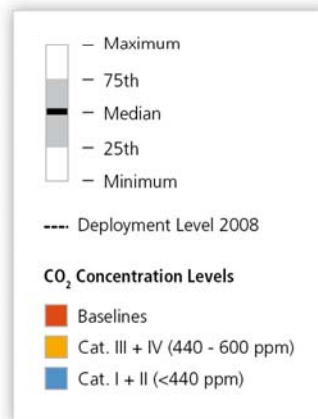
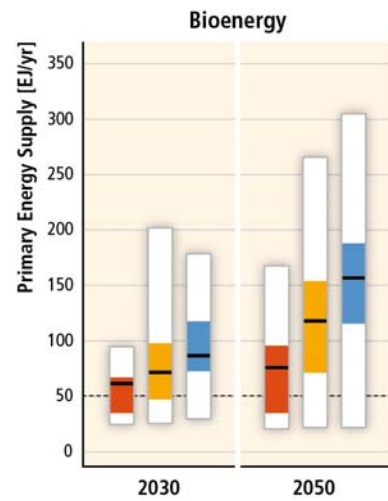
# High and low bioenergy scenarios both possible

## – whether sustainable depends on deployment

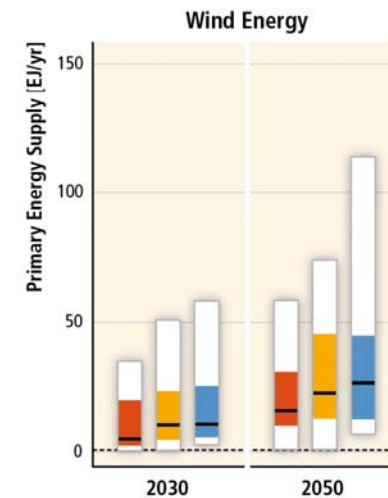
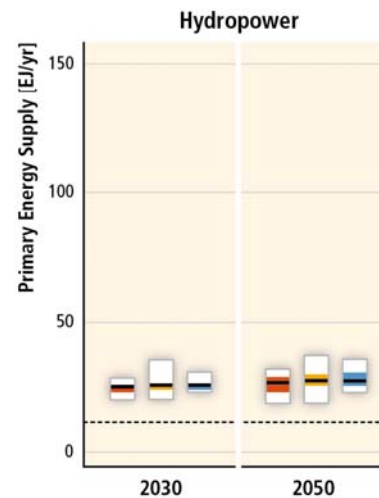
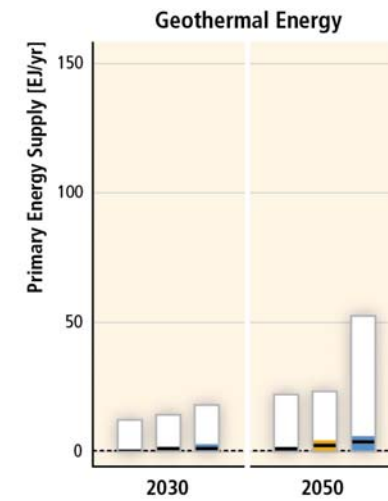
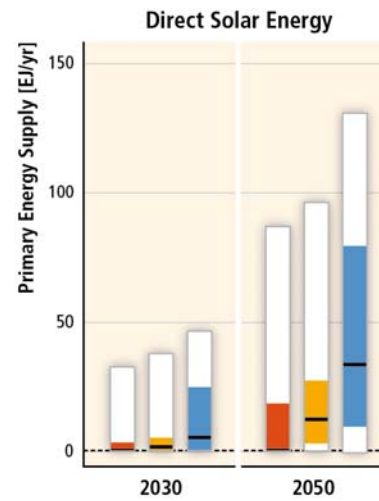




# RE deployment increases in scenarios with lower greenhouse gas concentration stabilization levels.

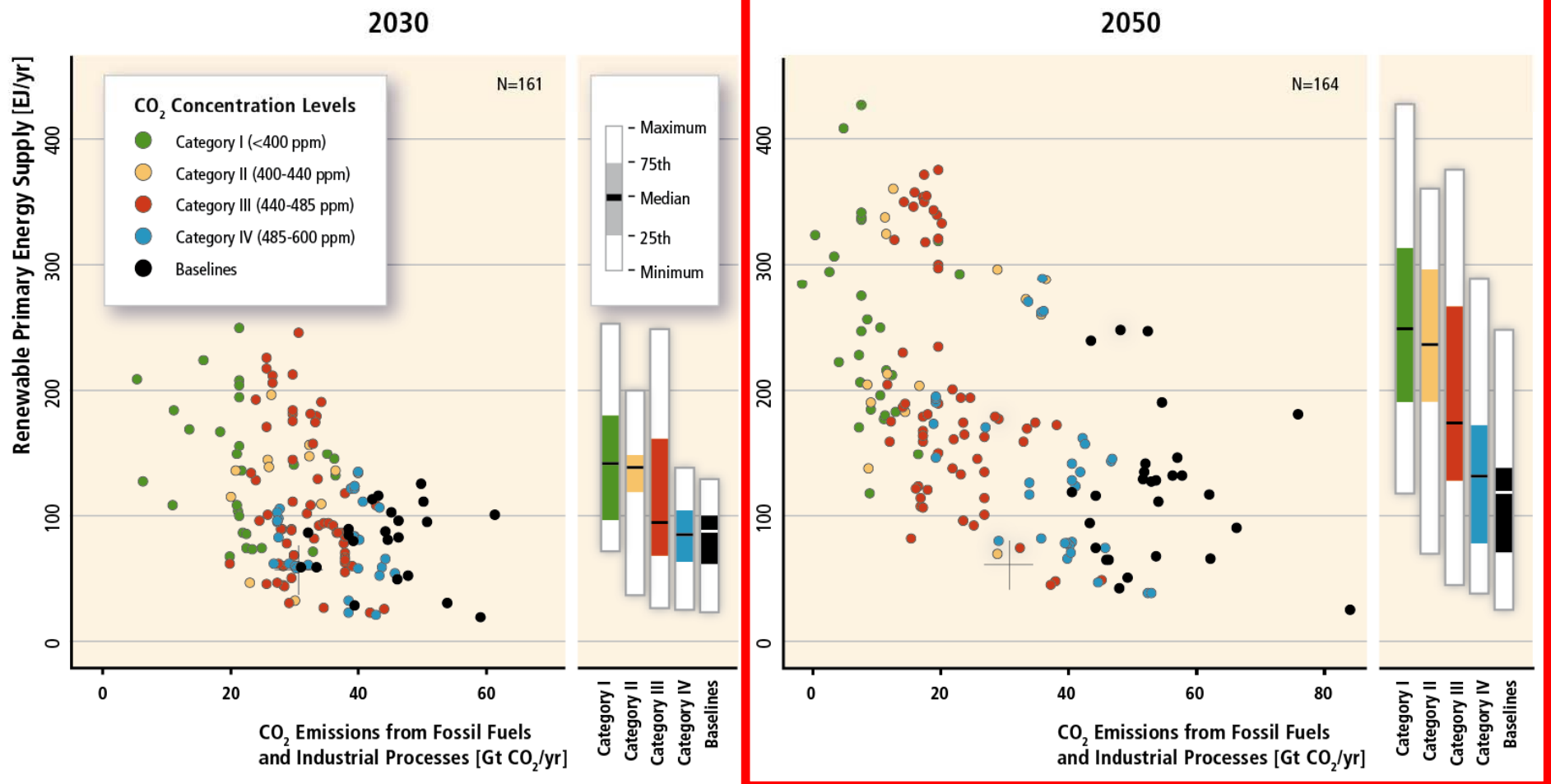


Bioenergy Supply is Accounted for Prior to Conversion

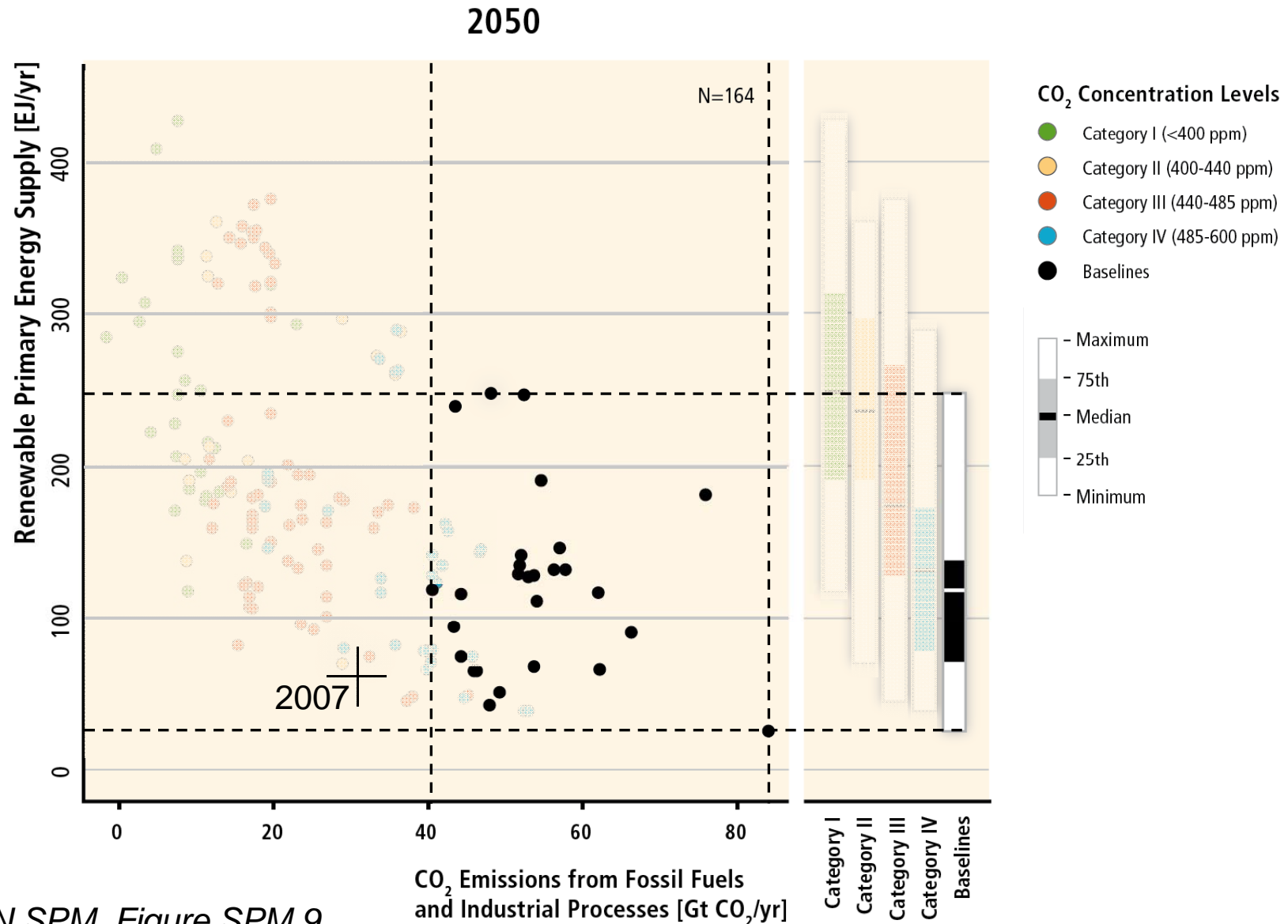


Primary Energy Supply is Accounted for Based on Secondary Energy Produced

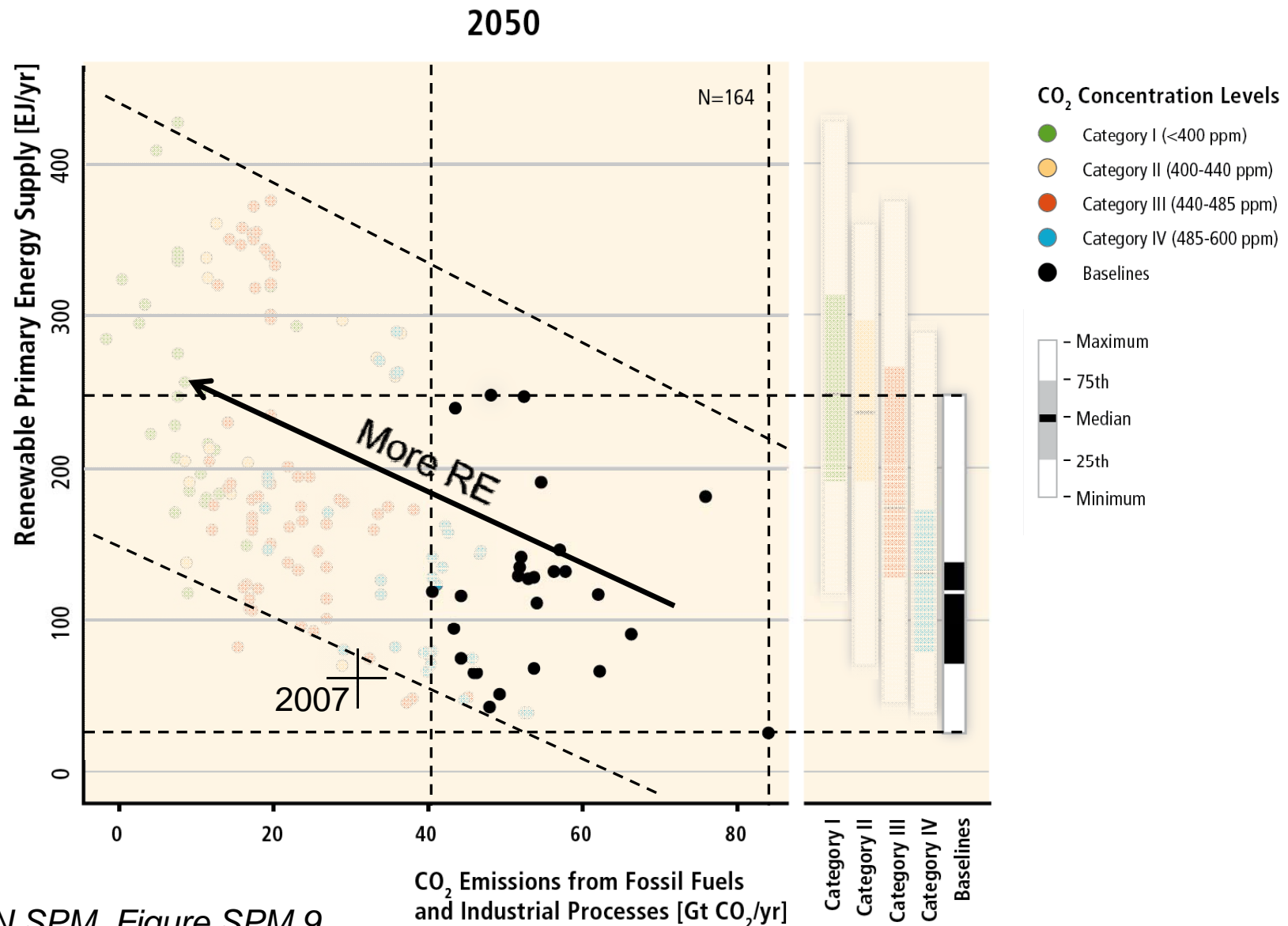
# Global RE primary energy supply from 164 long-term scenarios versus fossil and industrial CO<sub>2</sub> emissions.



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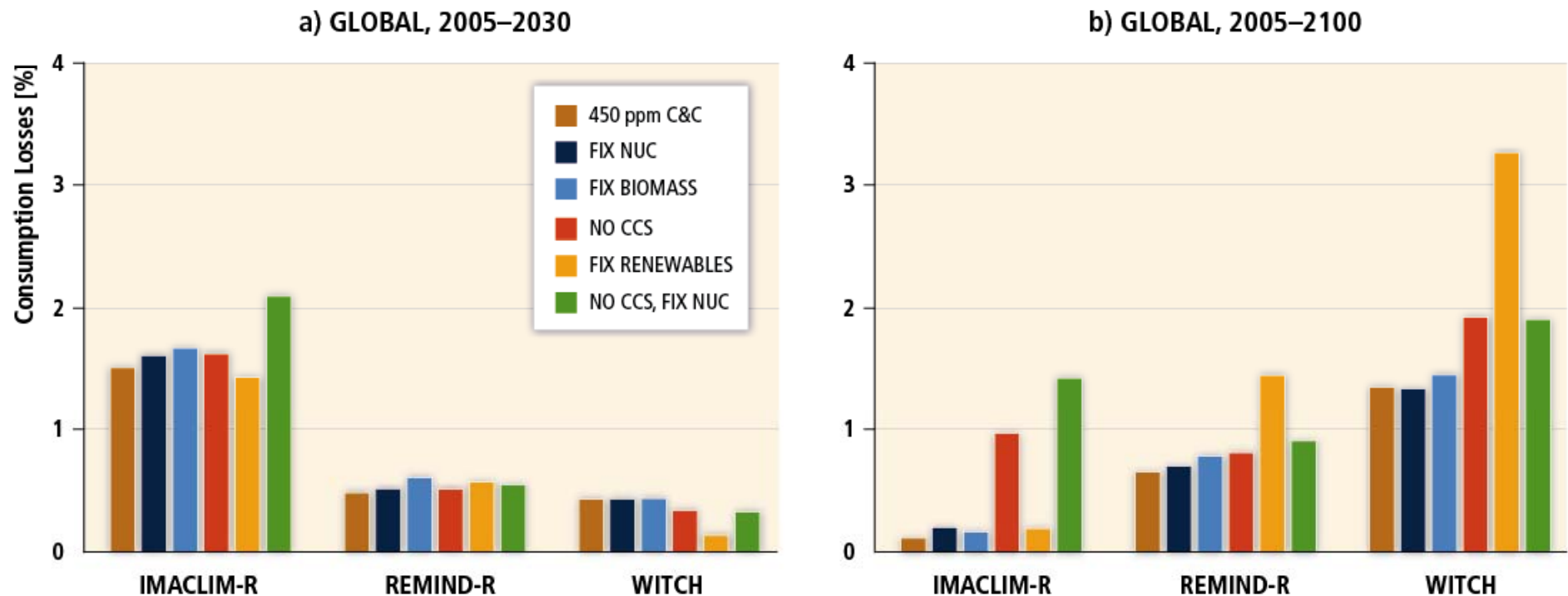


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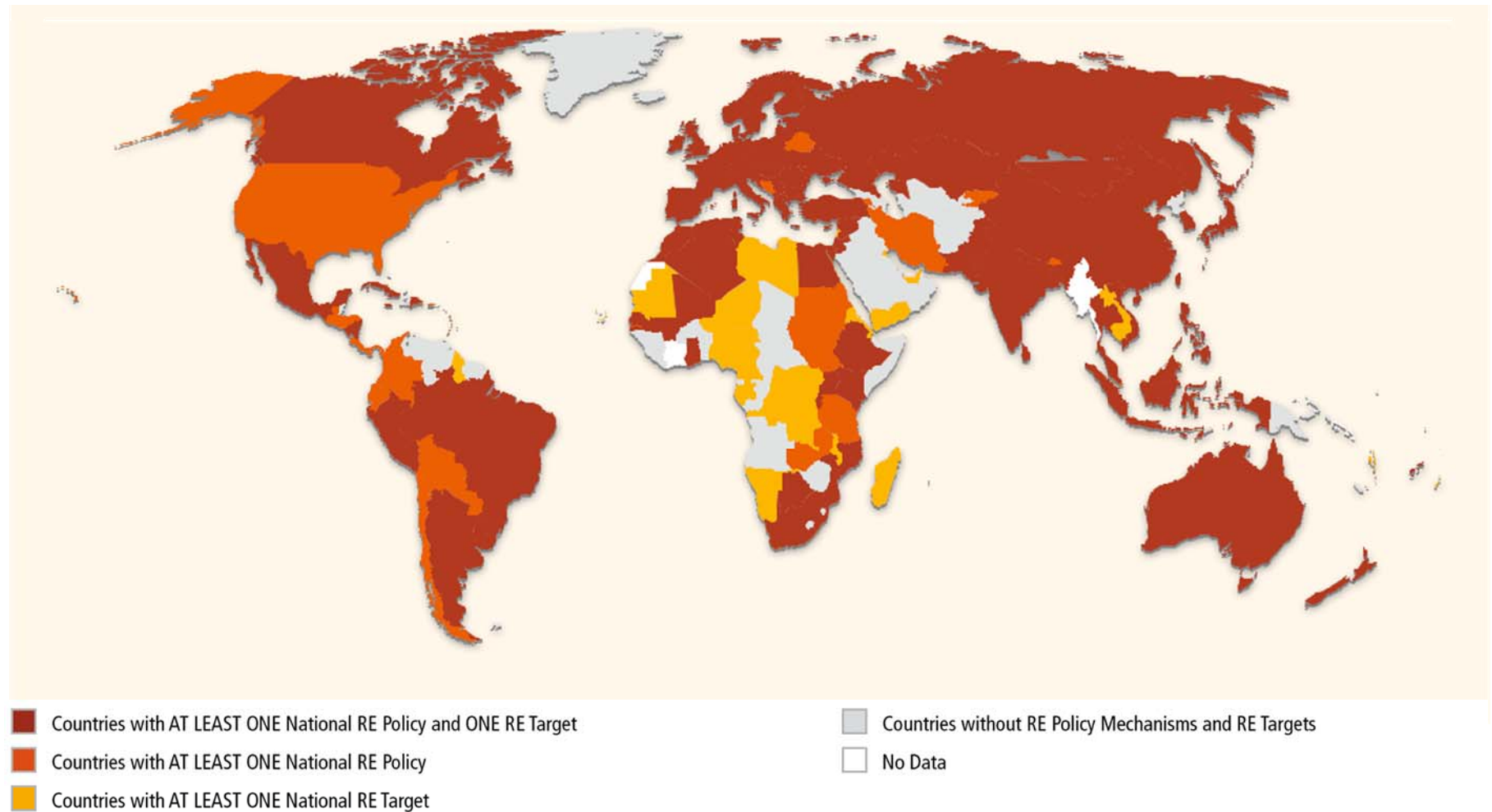
SRREN SPM, Figure SPM.9

# Macroeconomic costs

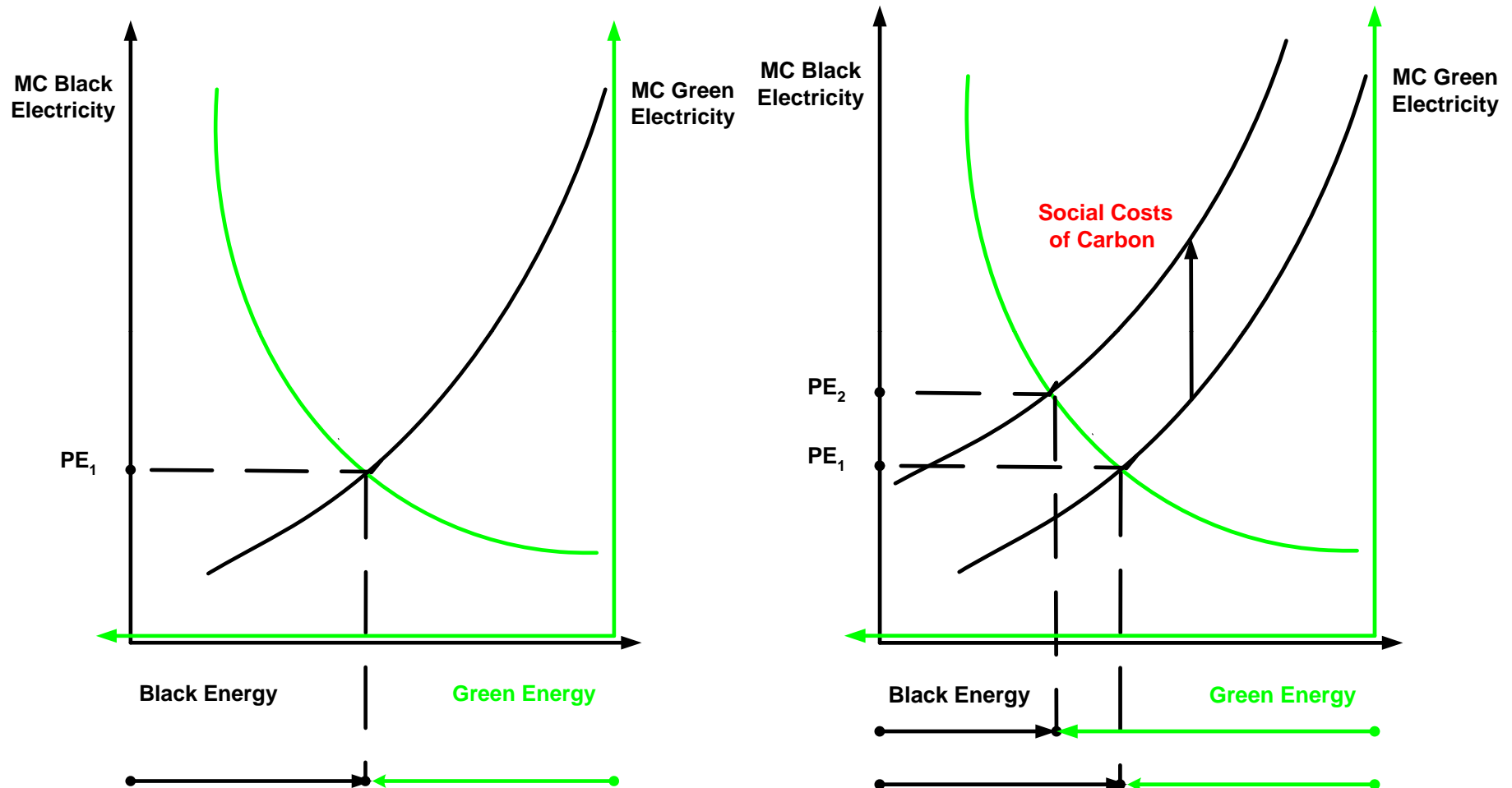


Edenhofer et al. (2011)

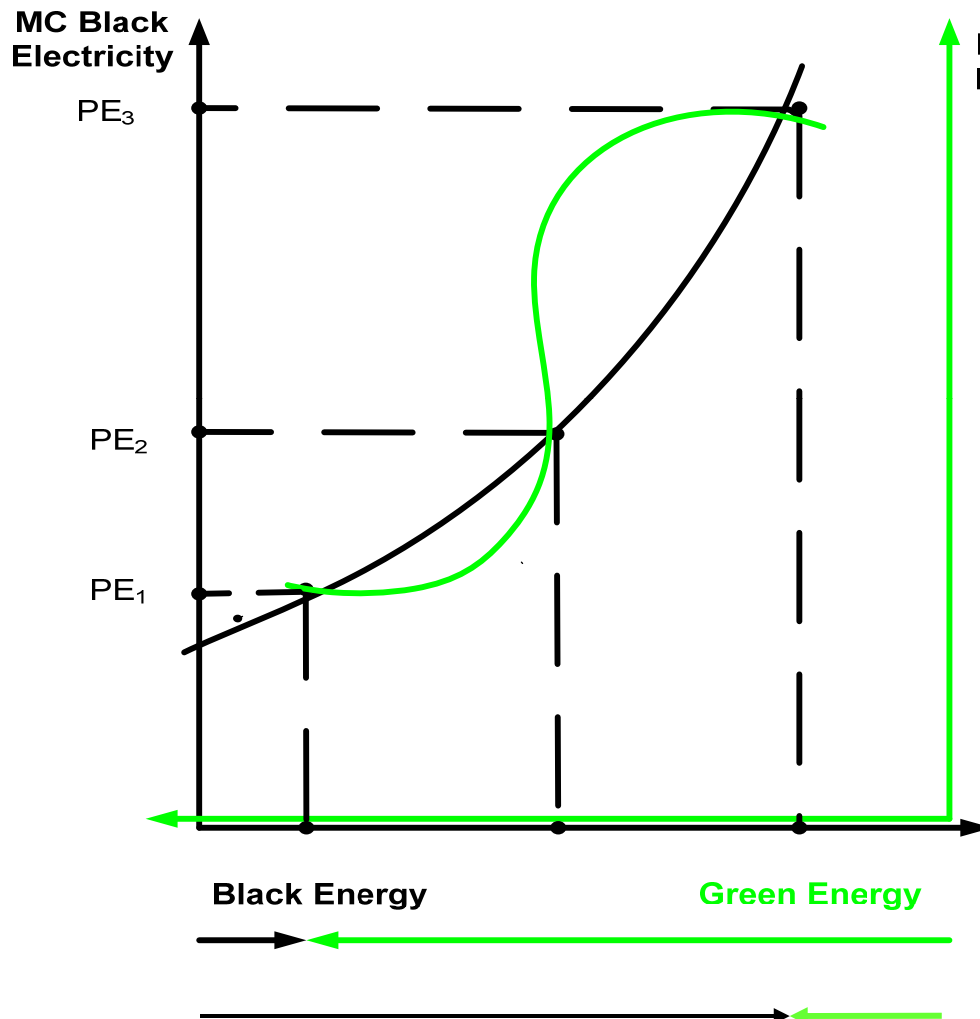
## RE-specific policies and RE targets (2011)



# How the main stream perceives renewable energy policy

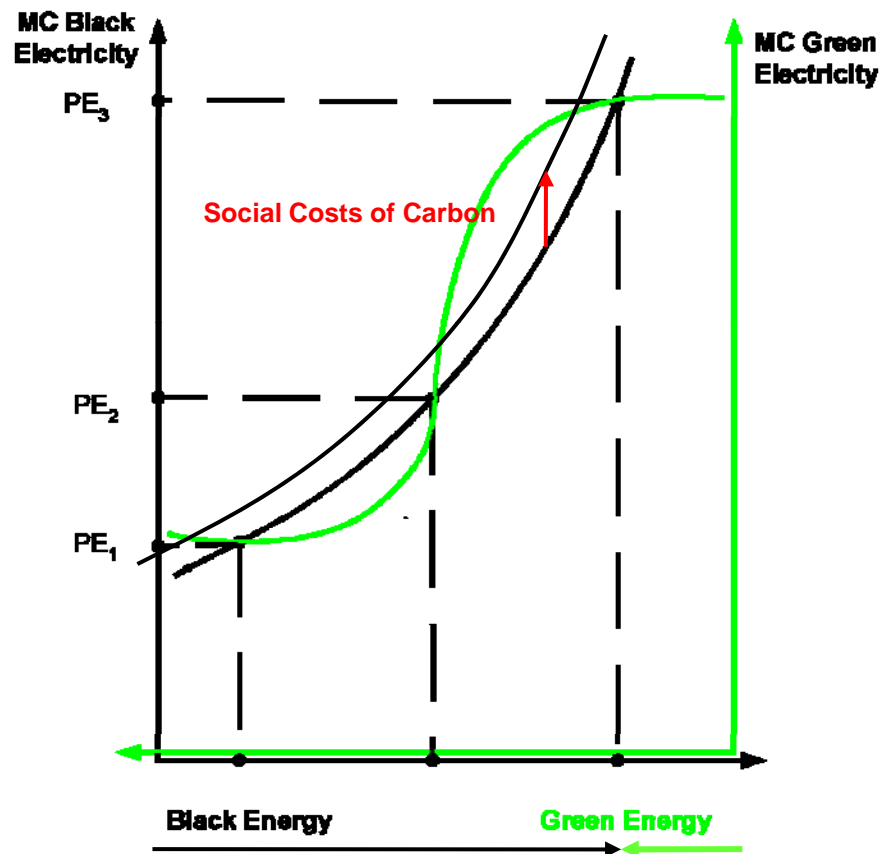


# A more realistic approach



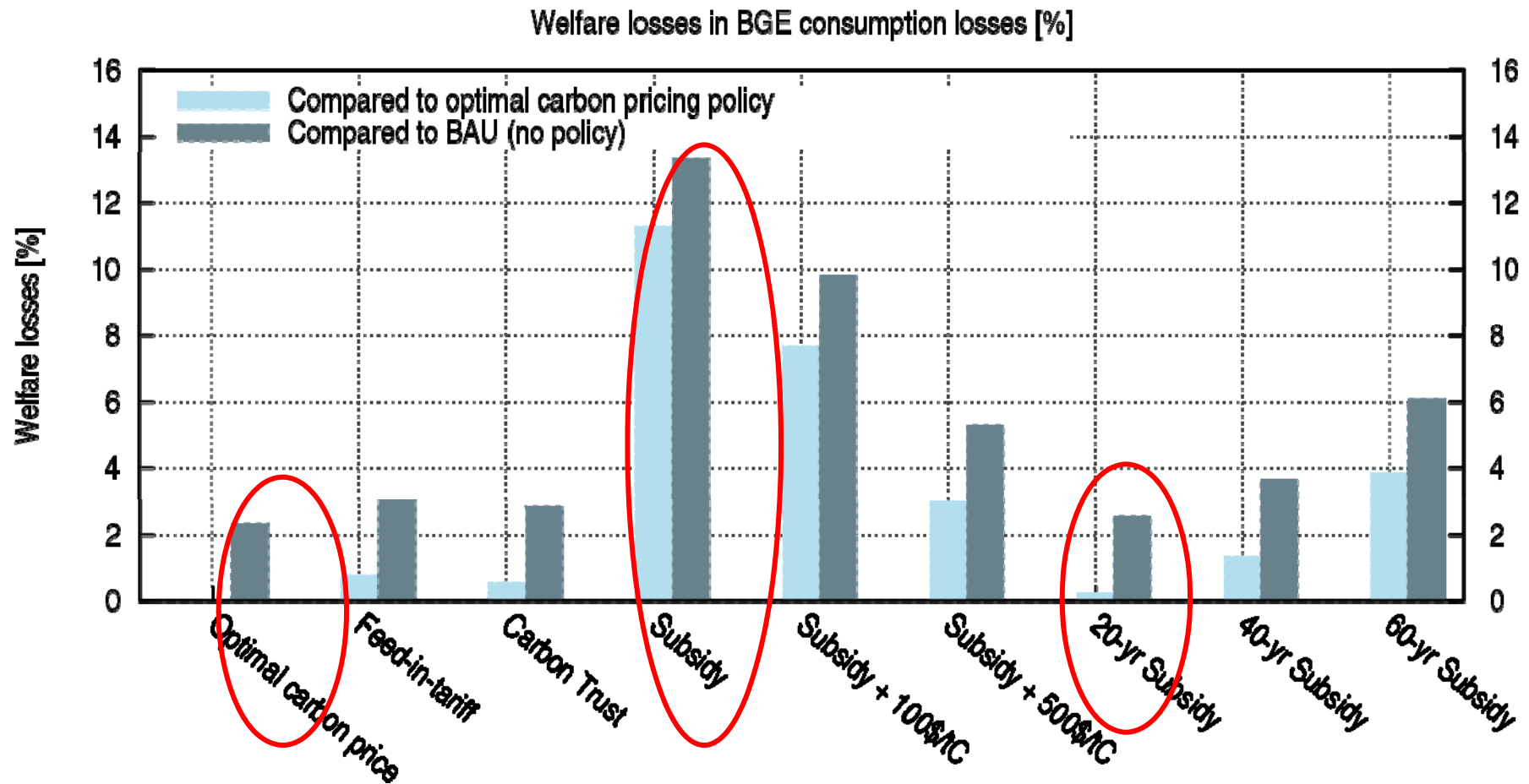
- Several stable equilibrium points ( $PE_3$  and  $PE_1$ ) are possible if the supply curves show a non-convex behavior ( $PE_2$  is not stable).
- Without additional policy support, the system will steer towards the neighboring equilibrium point  $PE_3$ .
- $PE_3 > PE_1$ : the system is **efficient**.

# 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.

# Renewable Energy Policy can be efficient



## **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 GHG emissions from 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.