The Price of Carbon Stabilization; Results of MERGE and GMM

Future International Actions on Climate Change-
Interpreting the Ultimate Goal, Estimating Costs, and Comparing Regime Designs

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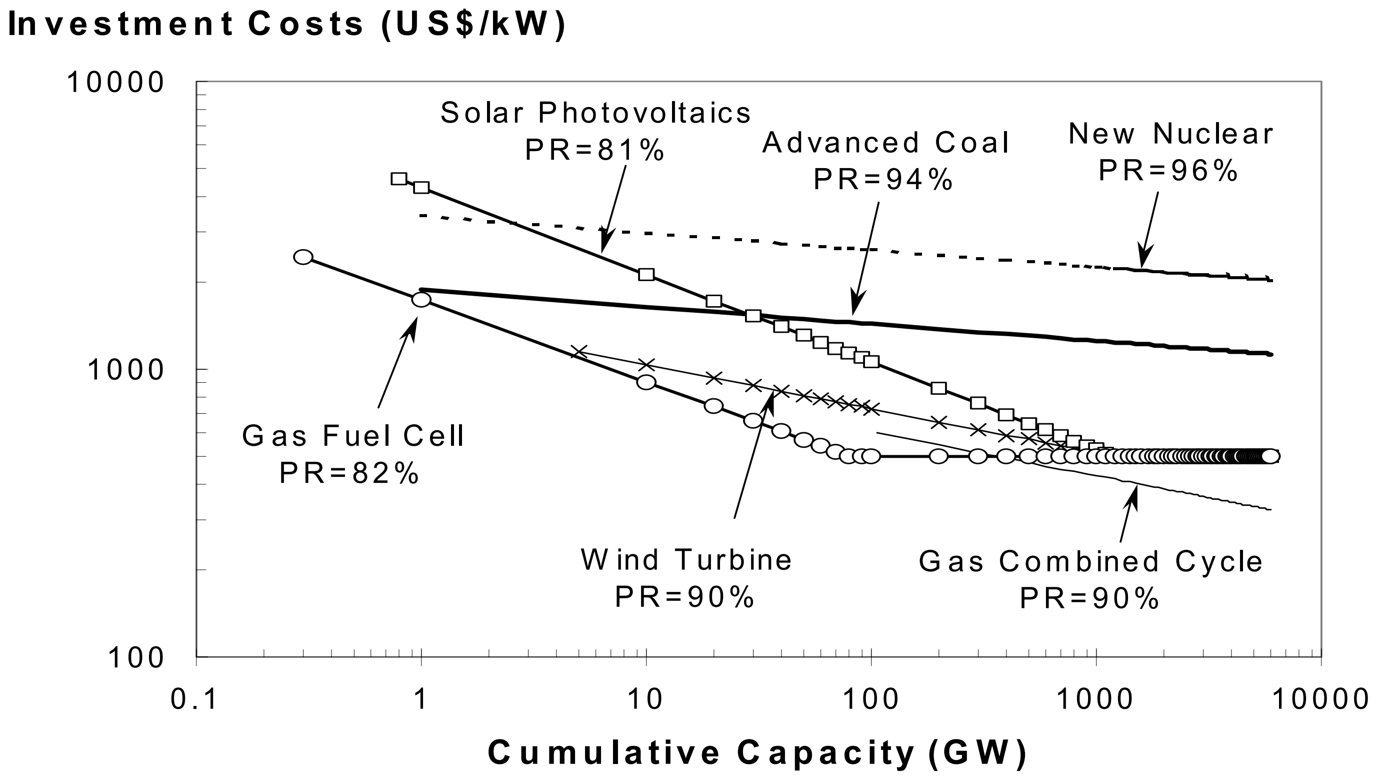
Modeling Experience Curves

$$SC_t / SC_0 = (CC_t / CC_0)^{-\beta} \cdot (KS_t / KS_0)^{-\gamma}$$

SC	**The Specific Cost of a technology in time t**
CC	**The Cumulative Capacity installations (represents LB-Doing)**
KS	**The Knowledge Stock (represents LB-Searching)**
β	**The learning by doing elasticity**
γ	**The learning by searching elasticity**

Learning curves assumed for some electricity generation technologies.

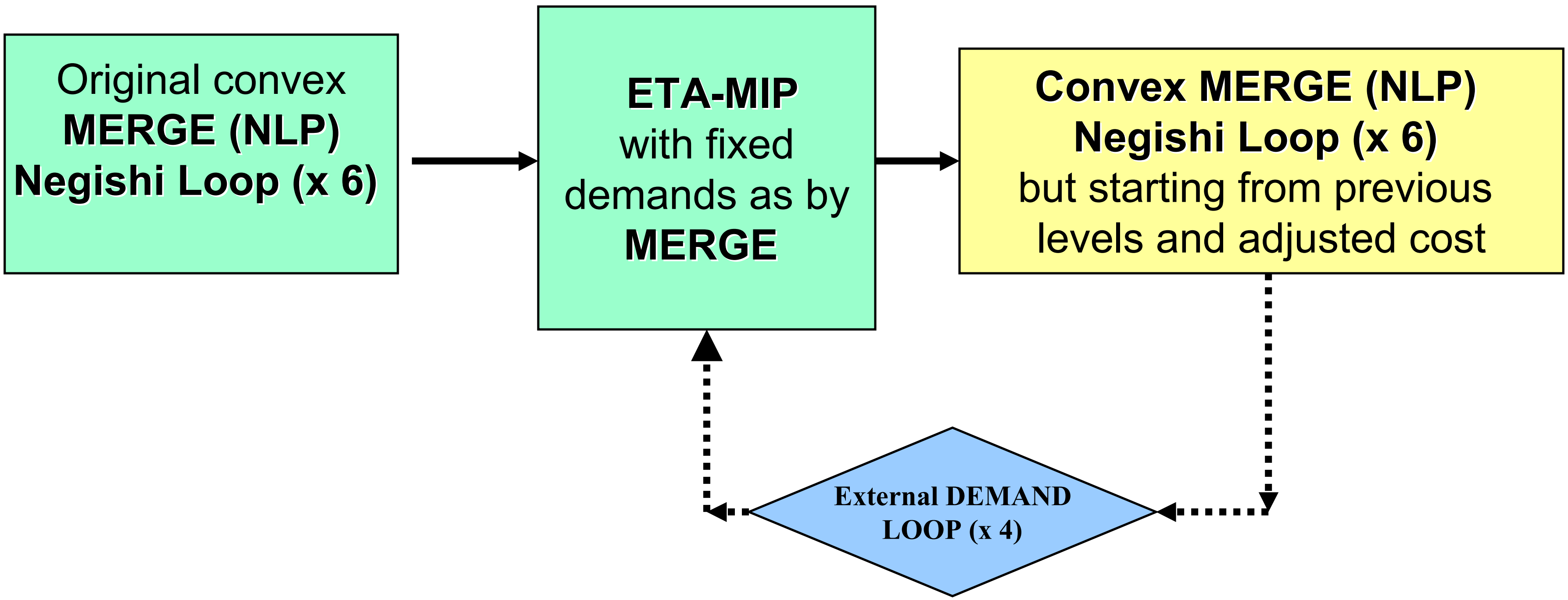


Technical data for systems used in MERGE-ETL

		Gen. Costs mills/kWh	Carbon Emissions Kg C/kWh	specific cost $/kW	load factor	life years	Learning rate (-)	floor cost $/kW
Electric Technologies								
HYDRO		40	0					
NUC		37	0					
GAS-R*		6.3	0.1443					
OIL-R*		6.3	0.2094					
COAL-R		20.3	0.2533					
GAS-N*		9.1	0.087					
GAS-A*		18.4	0.01	1010	0.7	25	0.11	550
COAL-N*		35	0.209	1300				
COAL-A		54	0.0068	2090	0.7	25	0.05	800
IGCC		34.7	0.193	1400				
IGCCR		46.4	0.026	1910	0.7	25	0.05	1000
ADV-HC		220	0	5000	0.25	25	0.2	1000
ADV-LC (Wind)		44	0	1000	0.25	25	0.11	400
NNU		40	0	2500	0.7	25	0.04	1000
Non-Electric Technologies								
		$/GJ	t C/GJ	$/GJ				$/GJ
CLDU		2.5	0.0241					
OIL1-OIL10	3.00-5.25		0.0199					
GAS1-GAS10	2.00-4.25		0.0137					
SYNF		8.33	0.4					
RNEW		6	0					
NEB -HC		14	0	13.3	1	20	0.15	4
NEB -LC		9	0	10	1	20	0.1	4

* Gas and oil systems do not include fuel cost

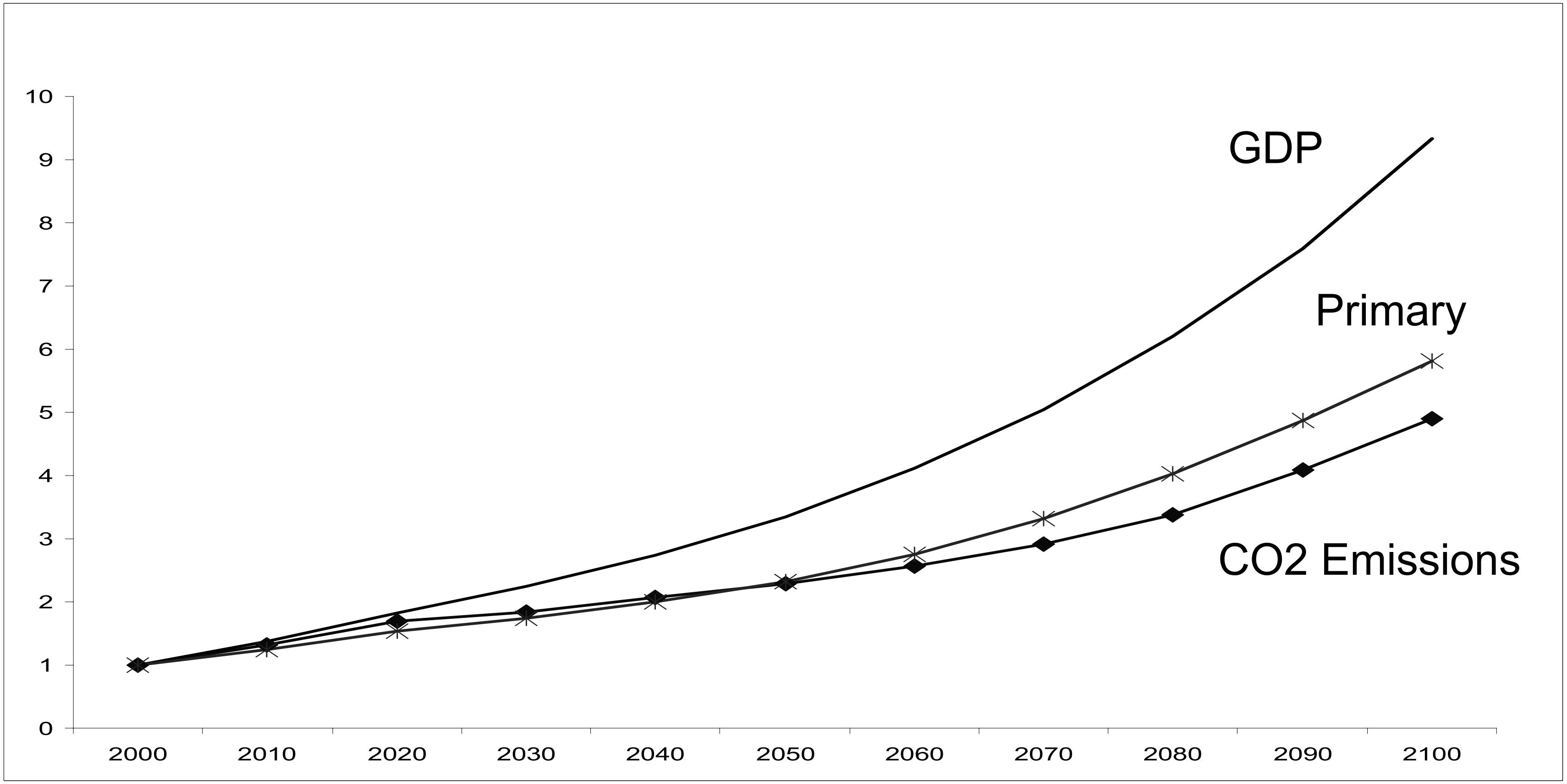
Solving MERGE-ETL



CO_2 case studies

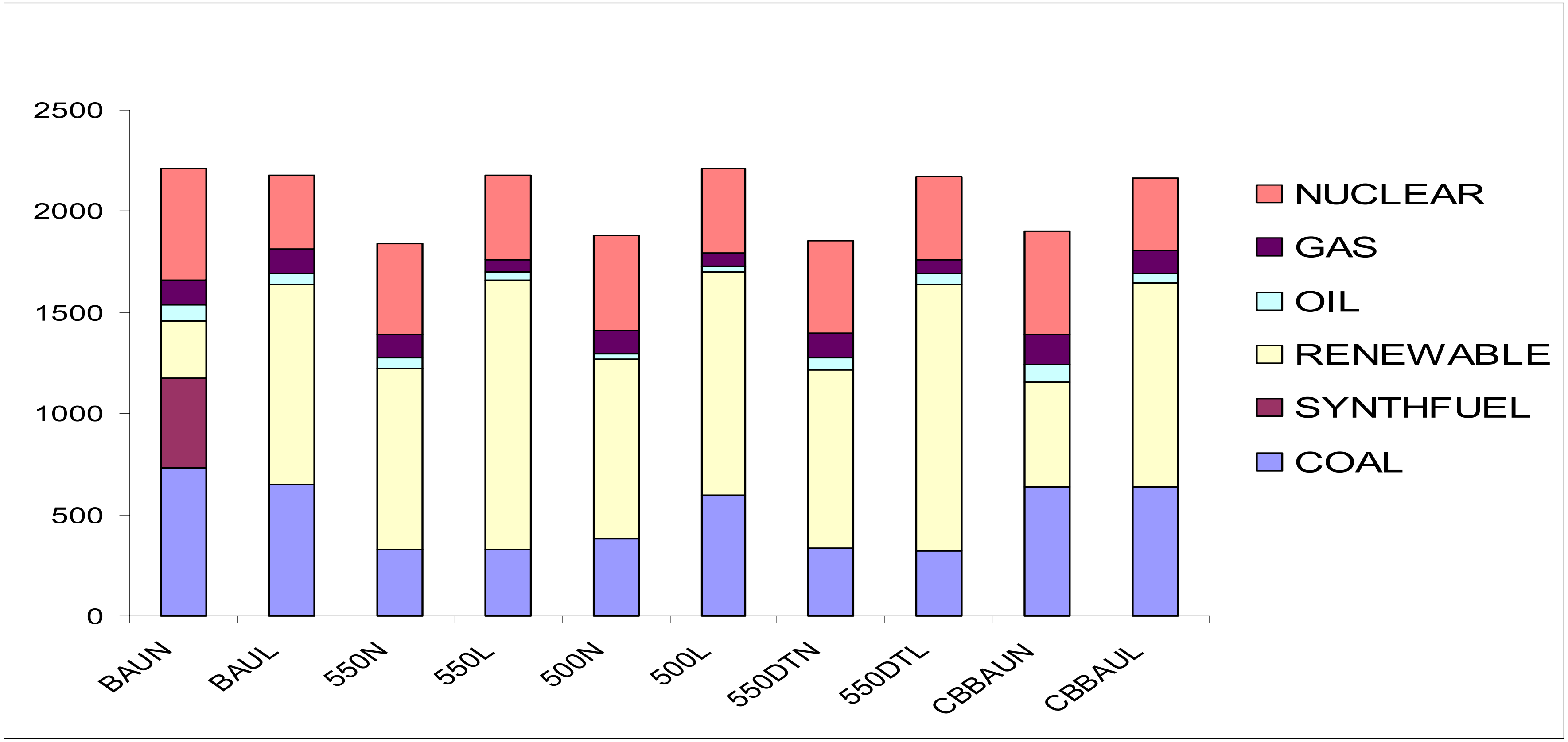
- BaUN (w/o LBD) and BaUL (LBD) : no CO2 limits
- Carbon Stabilization cases under full Carbon trade and global learning for:
  - 550 ppmv, w/o LBD (550N) and 550, w LBD (550L)
  - 500 ppmv, w/o LBD (500N) and 550, w LBD (500L)
  - 550, w LBD with limits in the rate of temperature change (550DT)
- C/B analysis

Baseline: GDP Energy and Carbon Indices

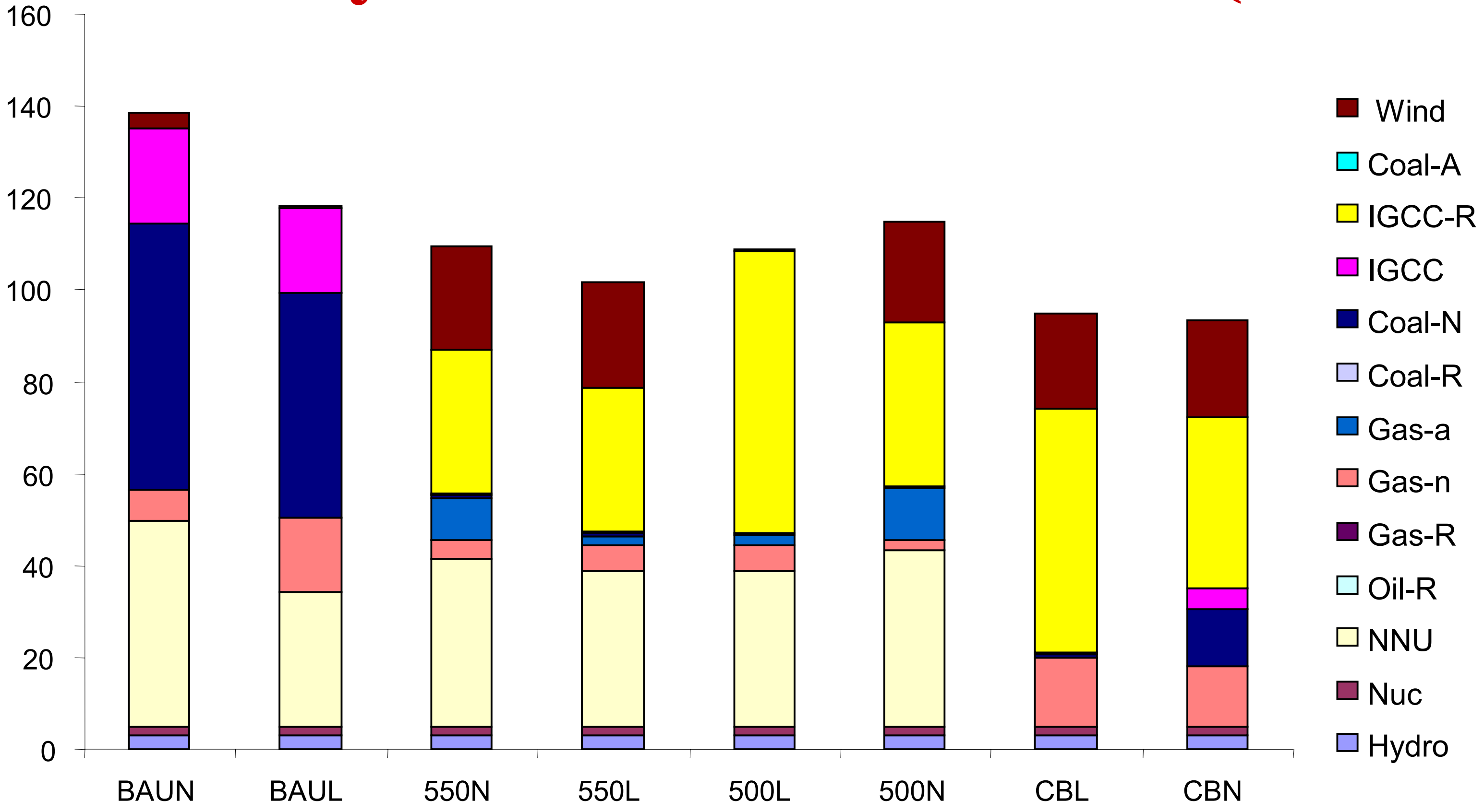


Primary by fuel in 2100 (EJ/a)

With LBD energy becomes a more competitive production factor with increased output of advanced renewables and new nuclear designs

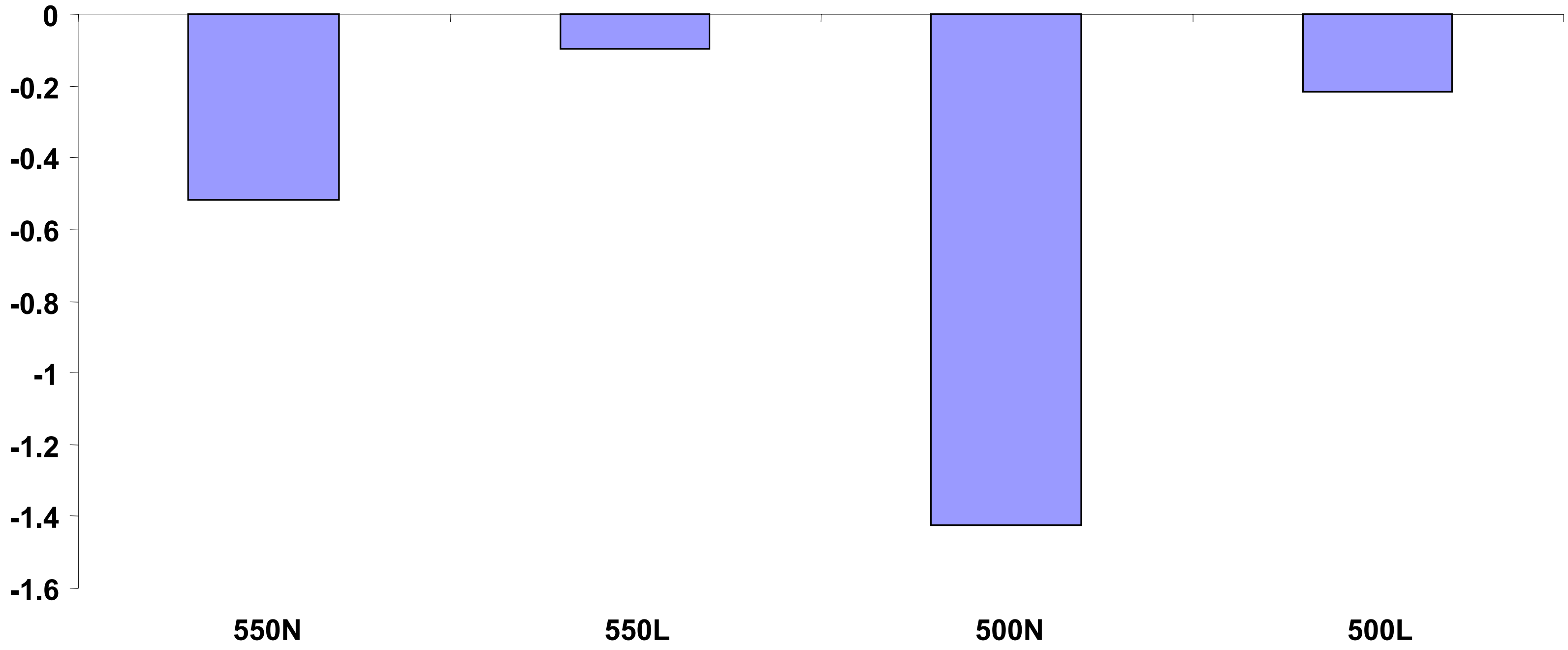


Electricity Production in 2100 (kTWh/a)



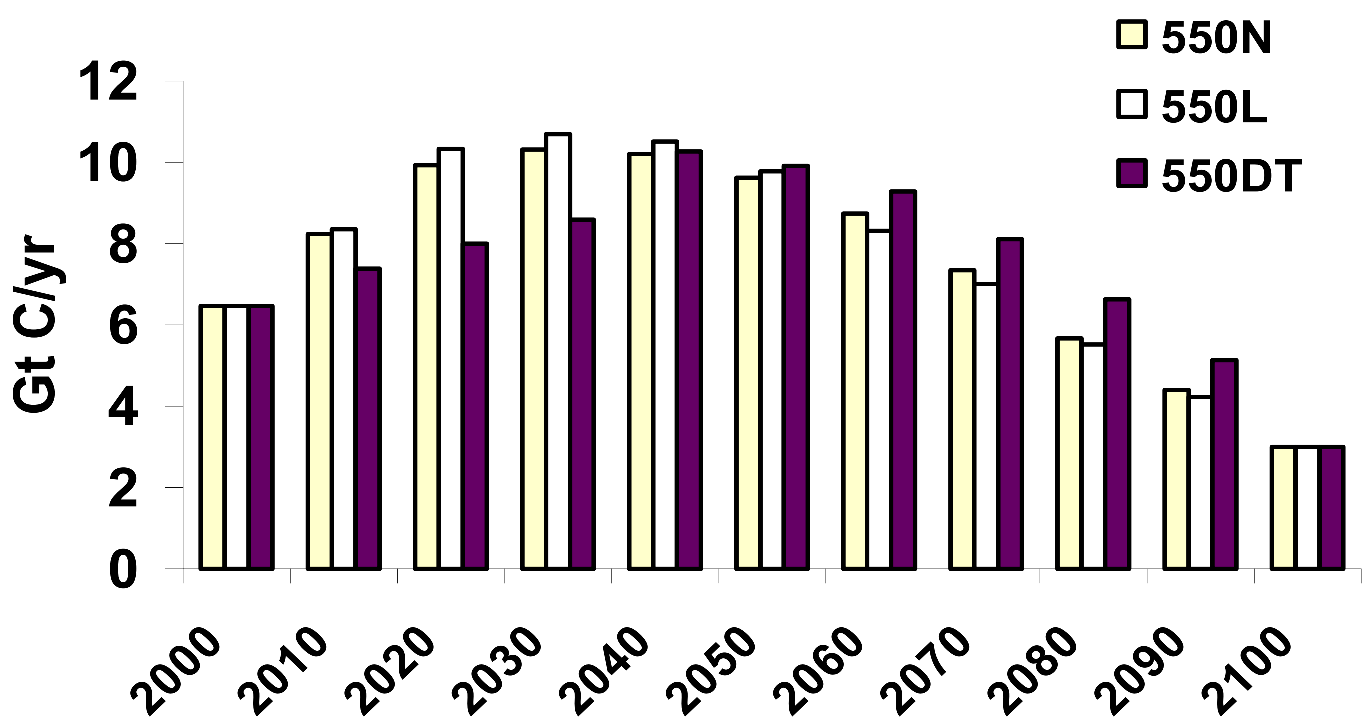
Under the carbon constraint IGCC with CCS, new nuclear and wind dominate.
In the reference case advanced coal, IGCC, and new nuclear dominate with contributions of gas CC and wind

Cumulative and Discounted GWP losses relative to BaUN



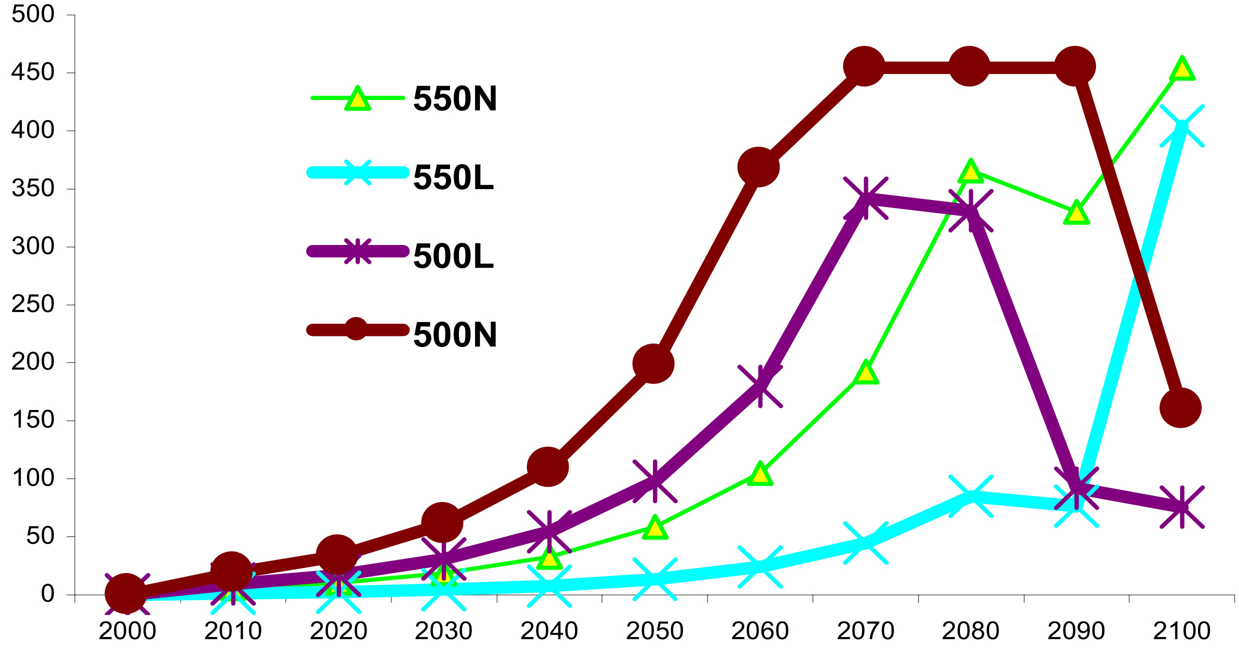
Losses are significantly reduced due to LBD; in the 550-ppmv-stabilisation case the cumulative losses (0.52%) are reduced to 0.1 % while in the 500-ppmv case losses are reduced from 1.42% to 0.22.

Emission Trajectories in GtC/yr



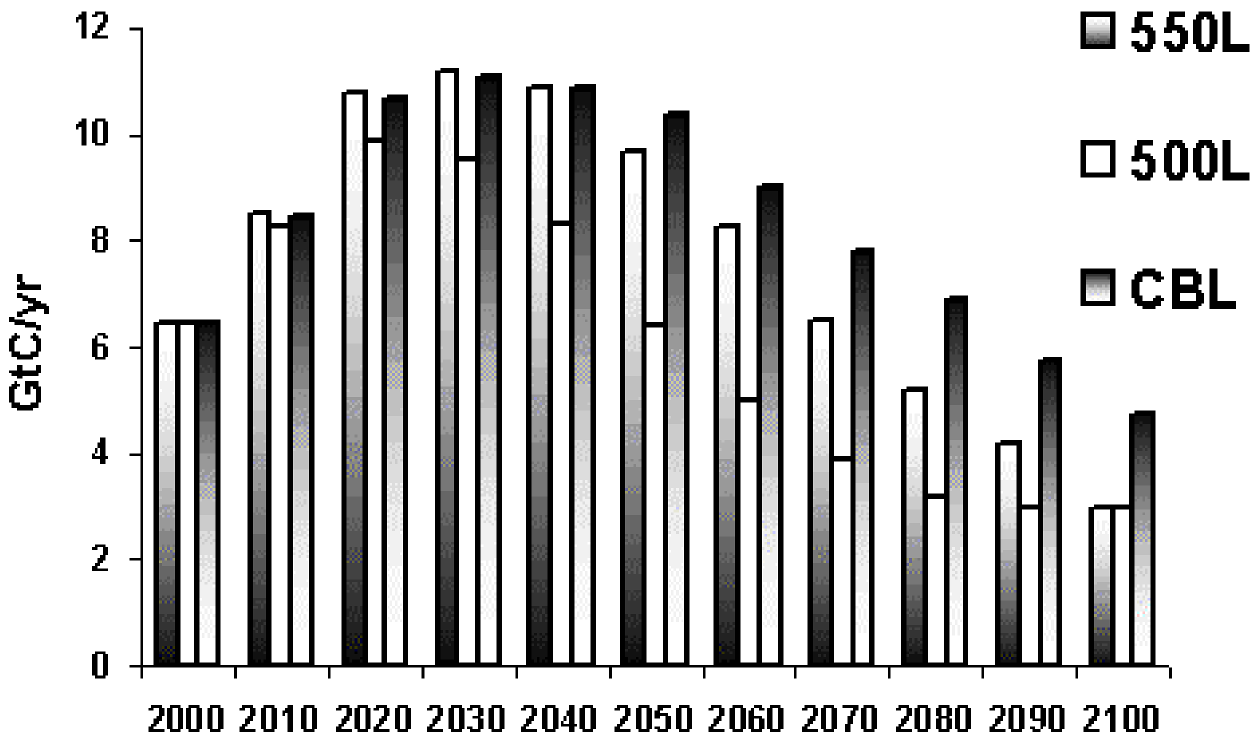
If applying a maximum temperature increase of 0.21 degree Celsius per decade (550DT), emission reduction is stronger than in the Kyoto protocol.

Marginal Costs in $/t C

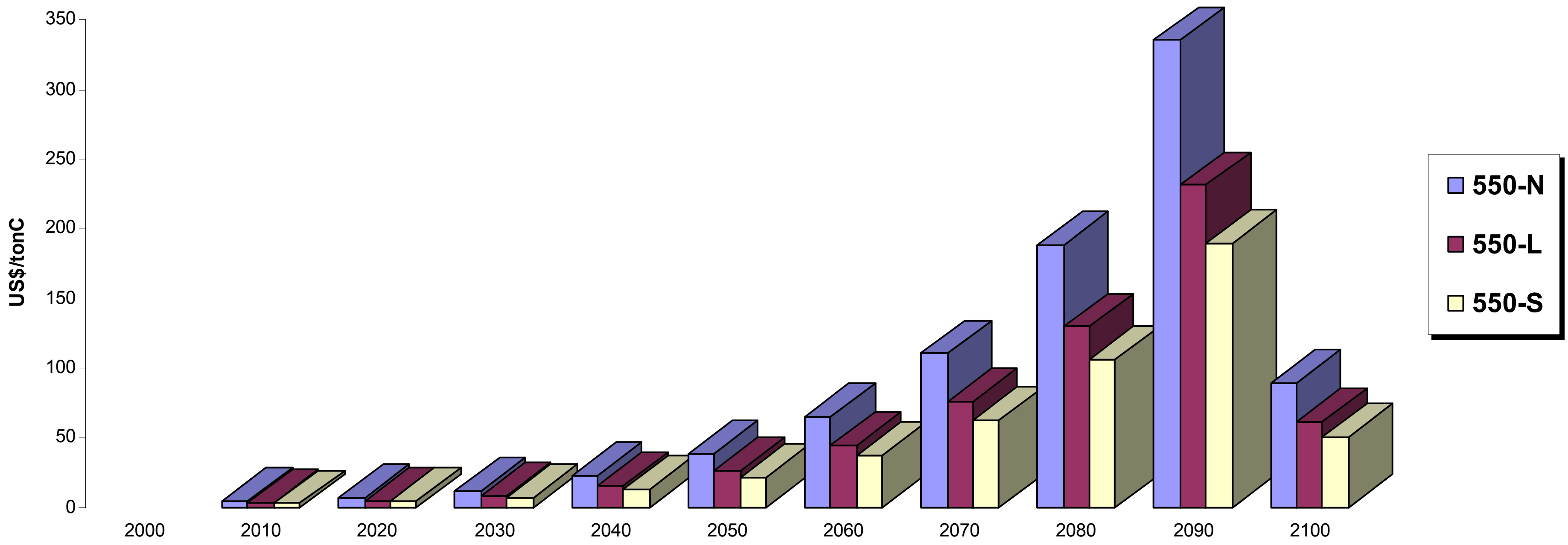


Under LBD policies the carbon price is reduced well below $100 per ton in the 550-ppmv case, and up to the year 2090

CO2 Emission Trajectories in GtC/yr

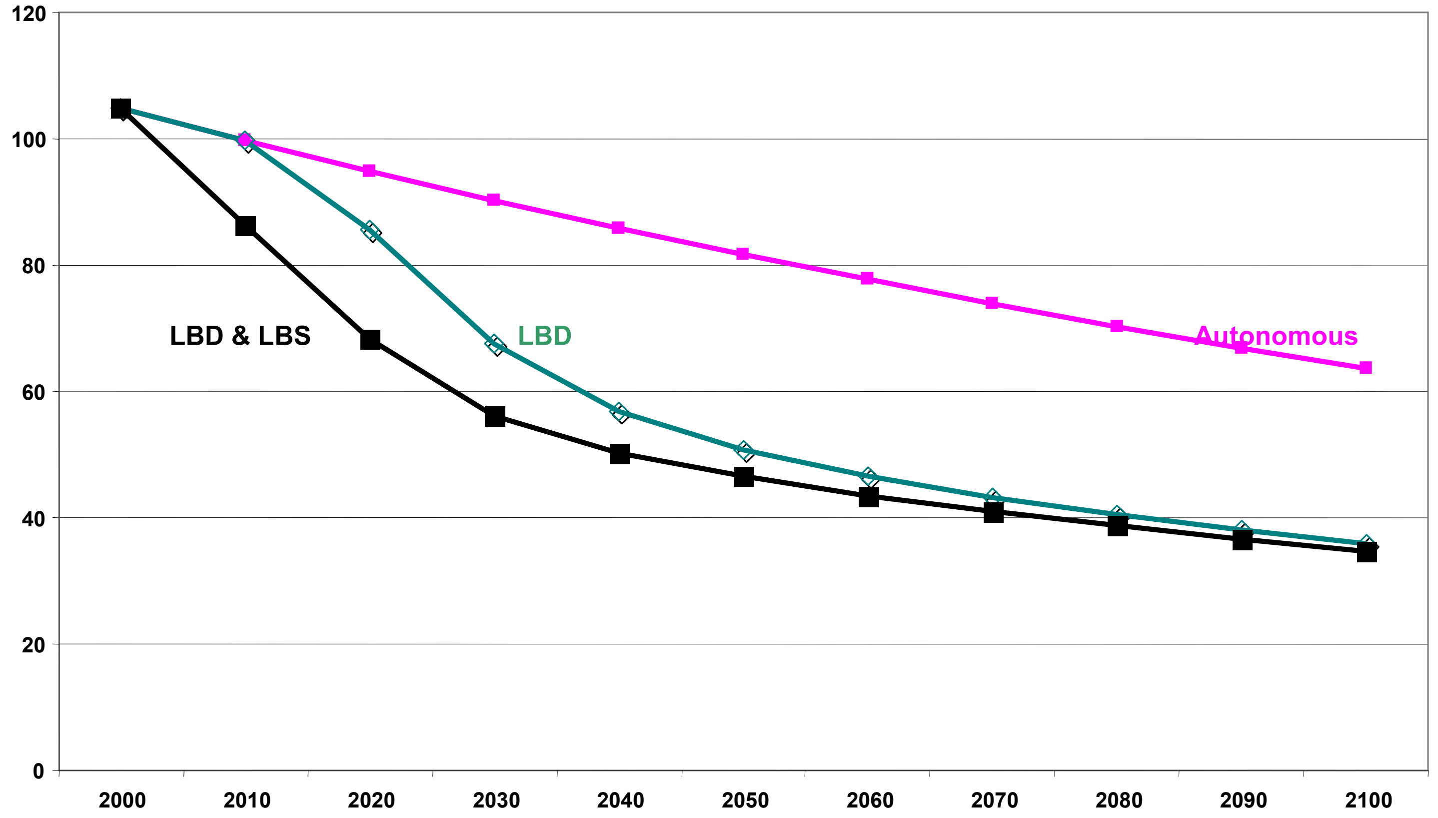


MERGE-TFLC; Carbon Price in US$/tonC

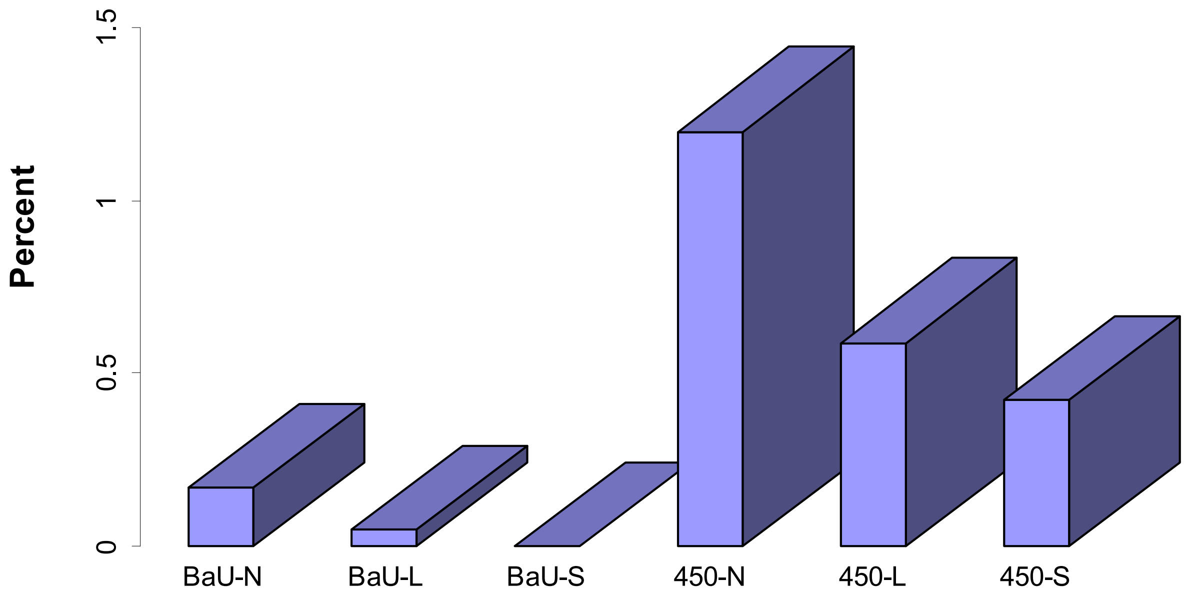


Generating Cost; Electric-Backstop; 450 ppmv

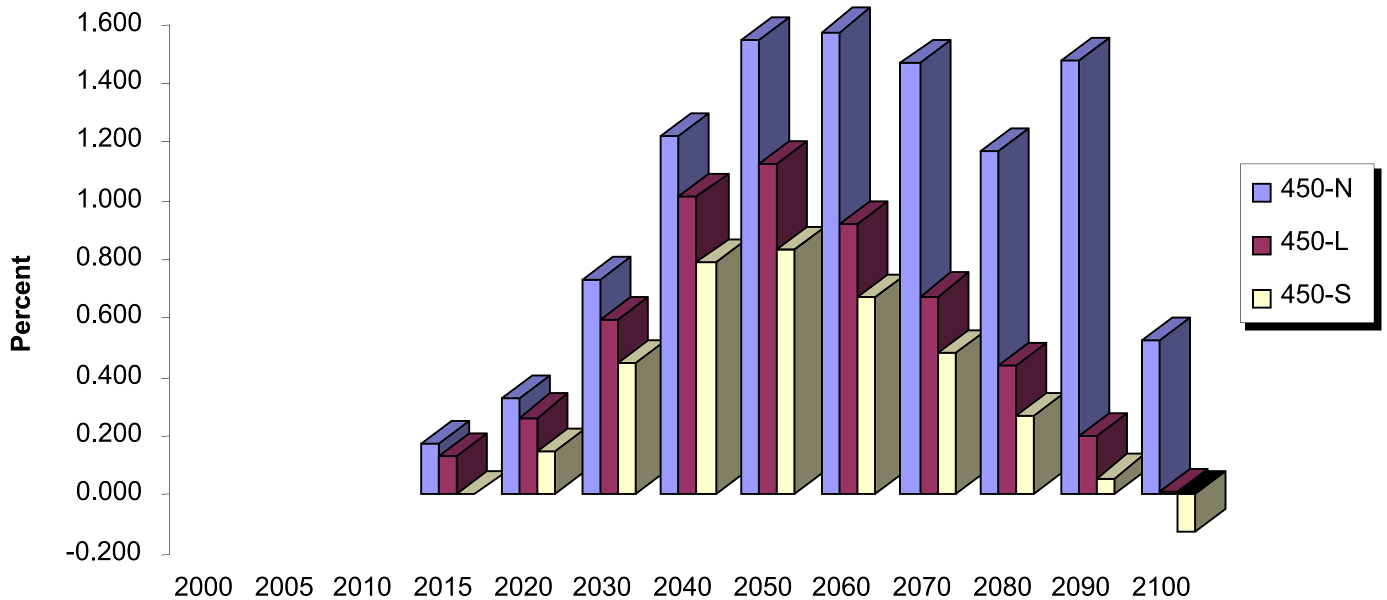
A significant cost reduction over time is shown when LBD applies.
RD&D policies are important in the early stage of introducing new technology.



Cumulative and Discounted GDP losses Relative to BaU-S in Percent



Annual GDP losses Relative to BaU-N in %



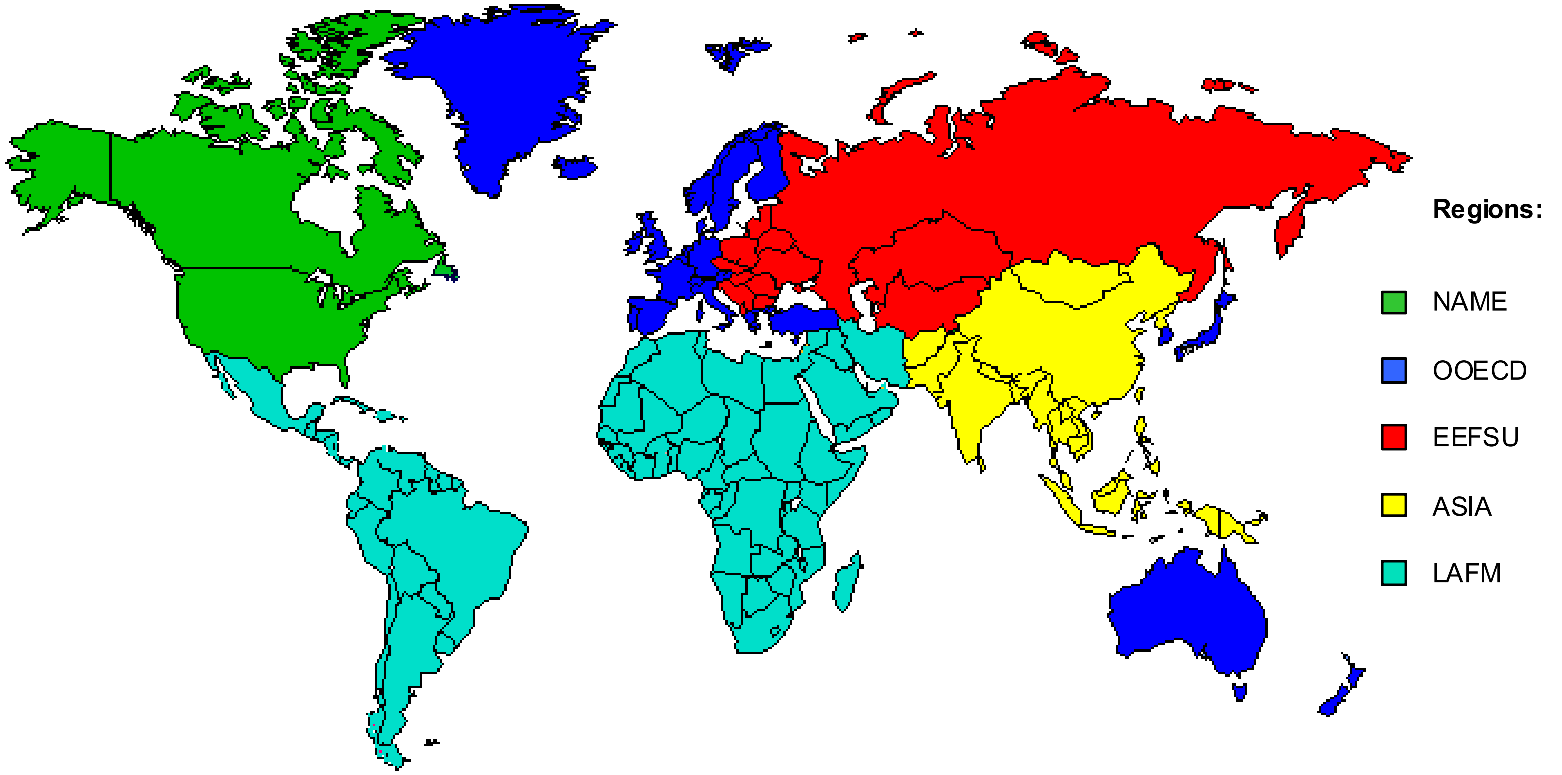
Conclusions of MERGE-ETL

- LBD supporting policies reduce emissions in the BaUL case
- The carbon price in the 550-ppmv case is below 100 $/ t C
- Cumulative GDP losses are between 1.4% to 0.25 % in 500-ppmv
- Kyoto type policies are well justified if a constraint of 0.21° Celsius per decade applies
- Most promising systems are
  - IGCC with CCS,
  - new nuclear designs,
  - wind and
  - other backstop renewables for non-electric

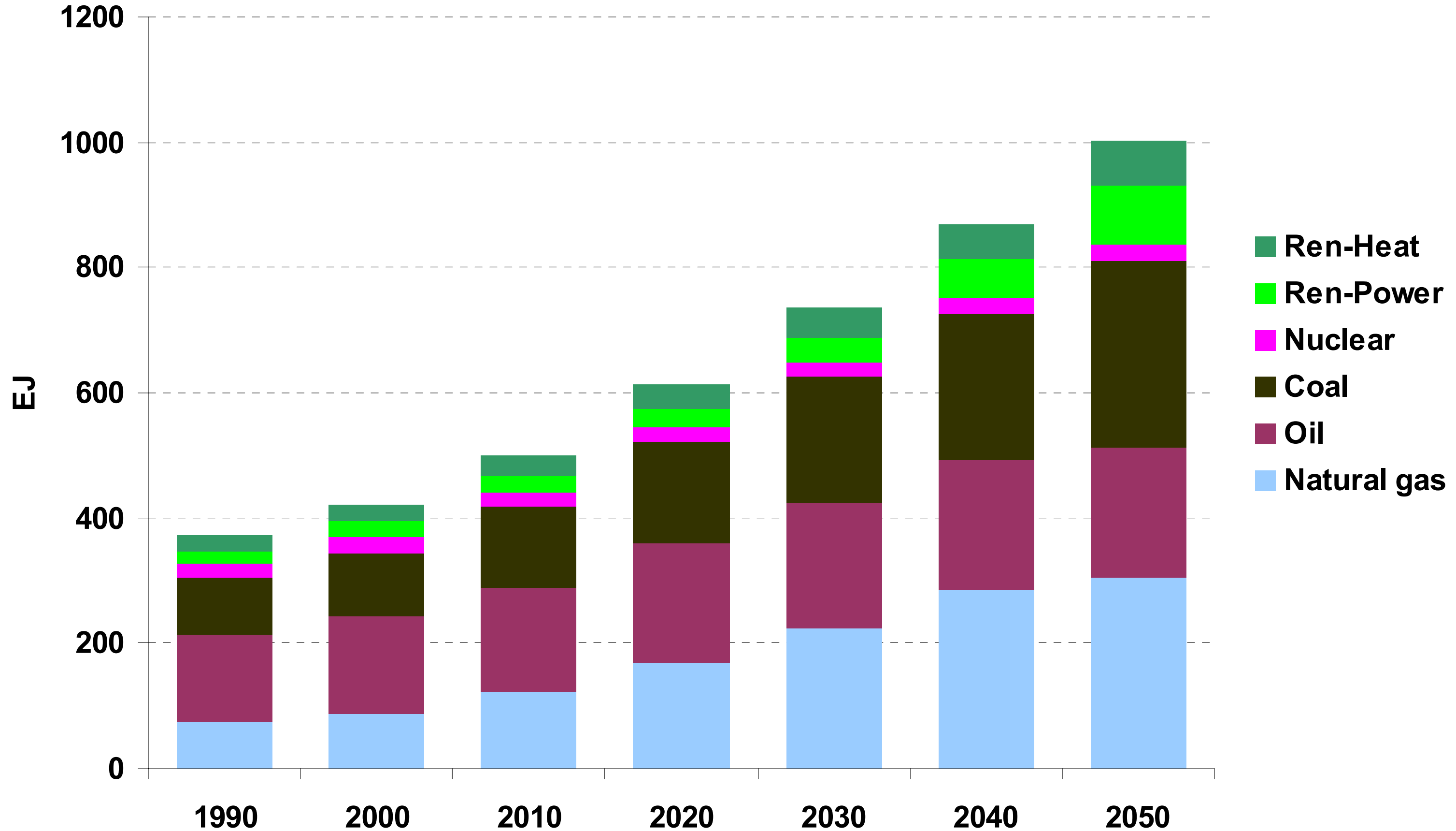
GMM; Model Characteristics

- A partial equilibrium LP "bottom-up" model (2060)
- Five world regions: North America, OOECD, Eastern Europe and Former SU, Asia and the Rest of the World
- Endogenous technological learning (LBD and LBS)
- Learning spill-over across regions and technologies
- Global trade of energy/environmental commodities
- A multi-gas model

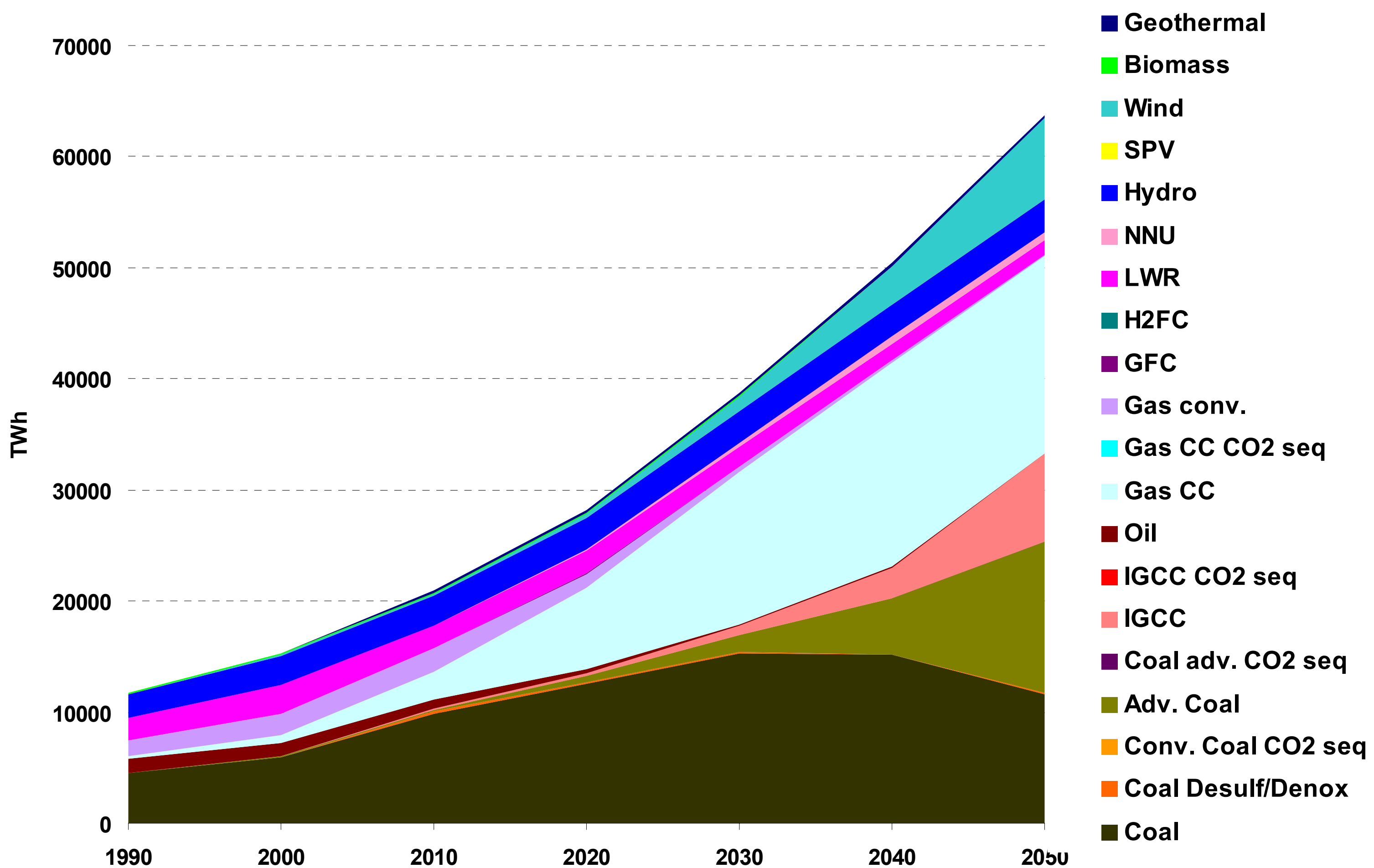
World Regions in GMM



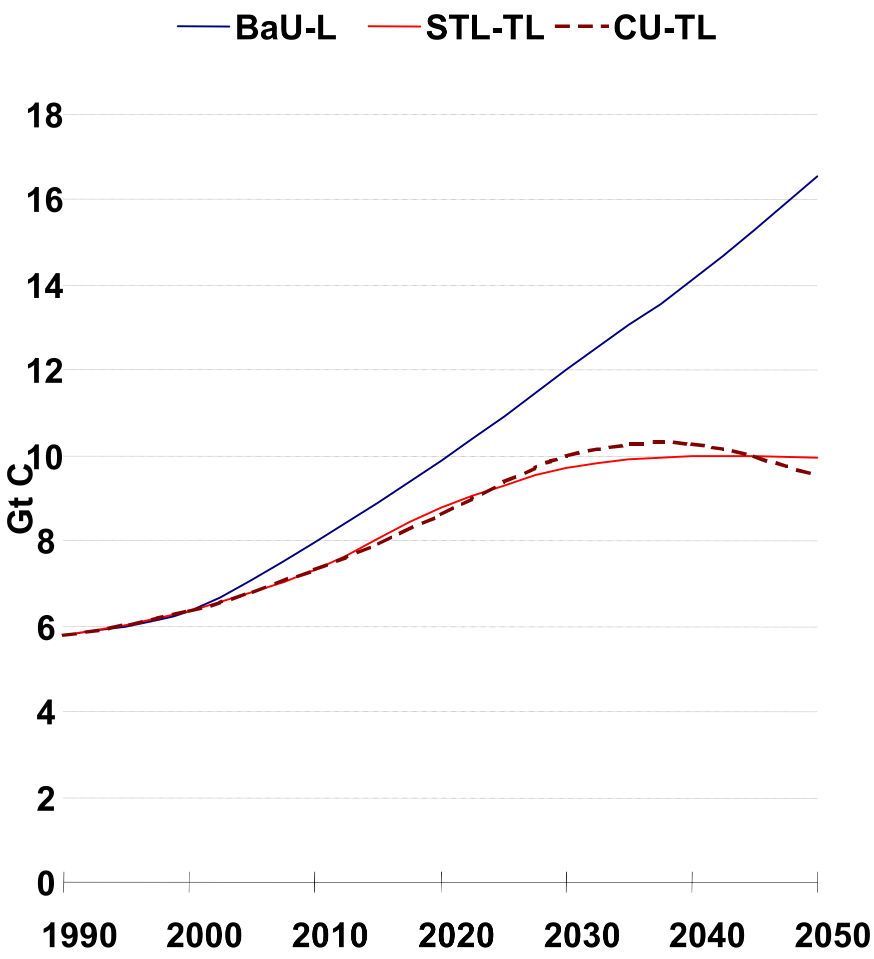
Baseline; Global Primary Energy

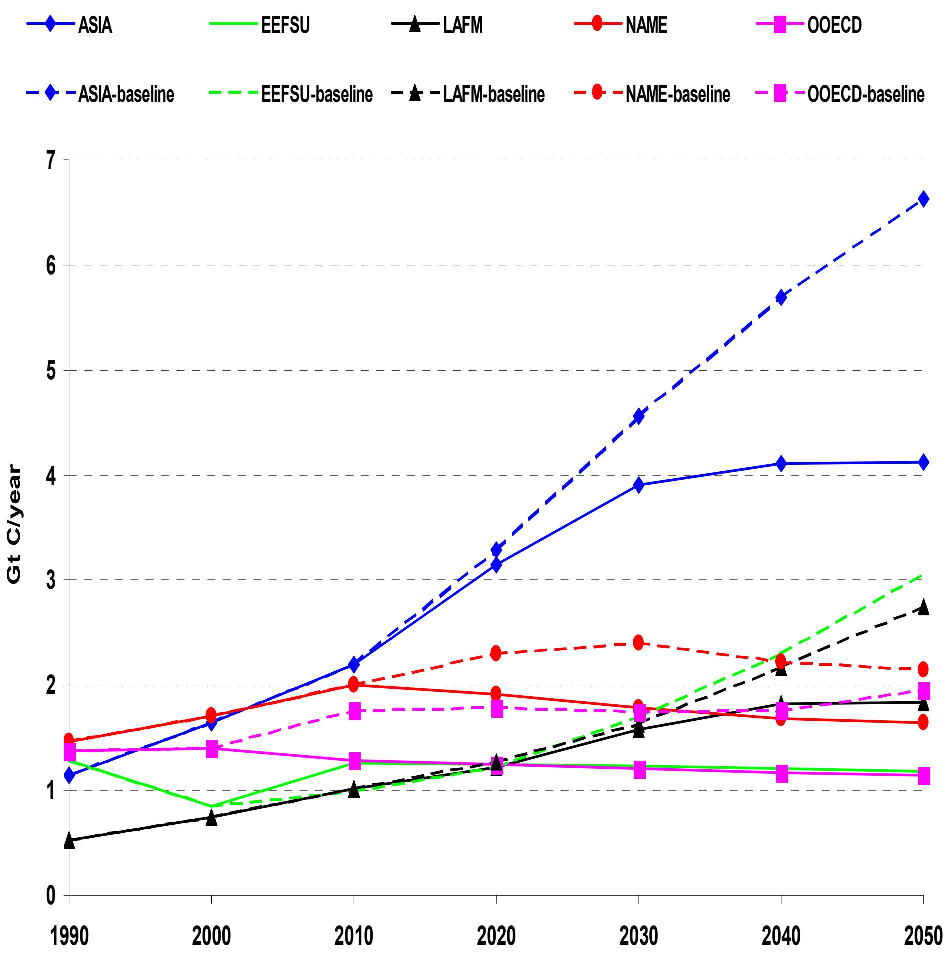


Baseline; Global Electricity Generation

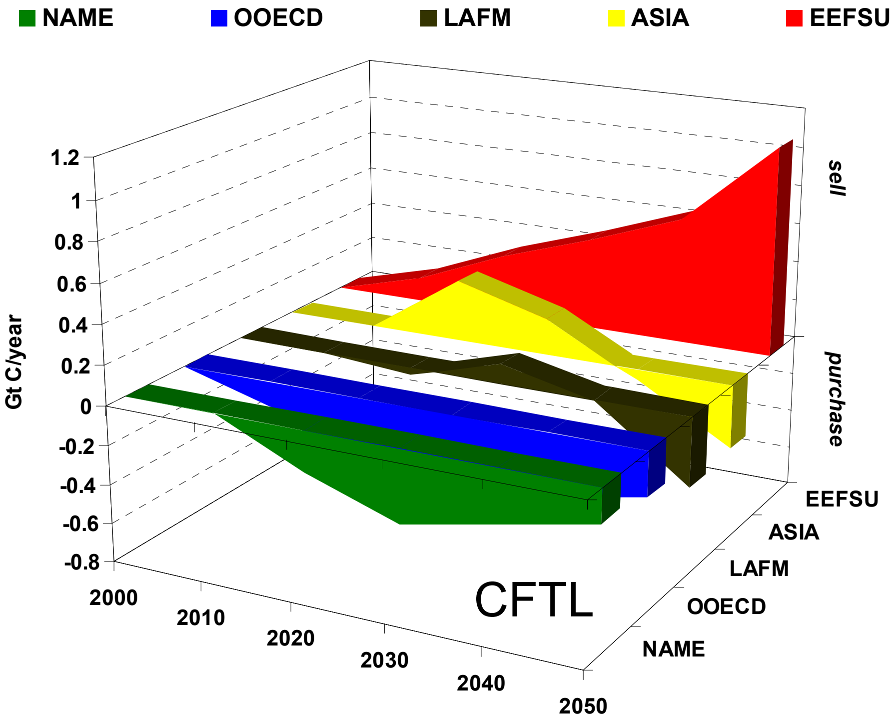


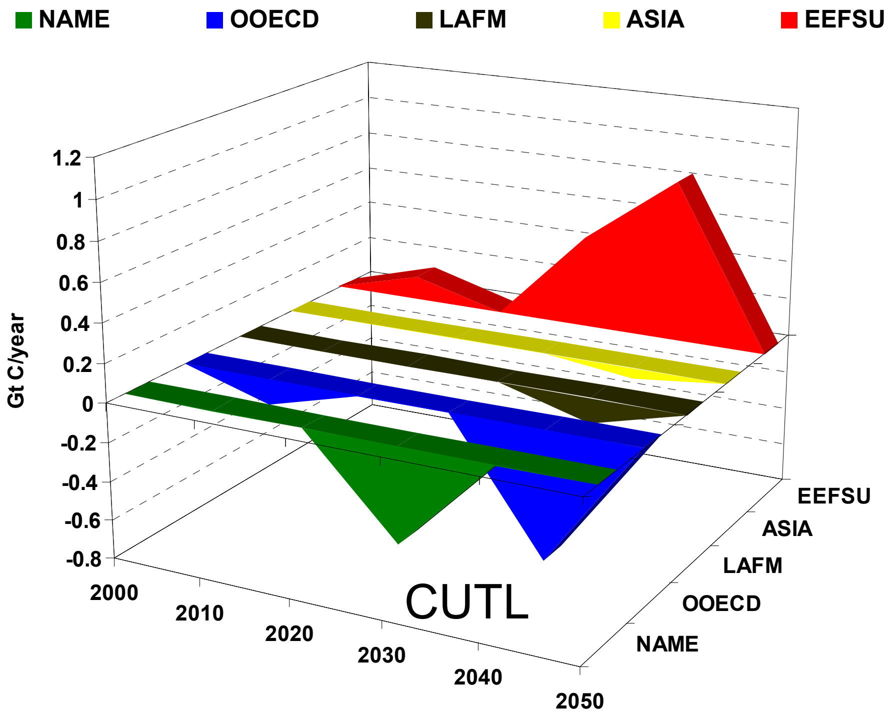
Soft – Landing Emission paths



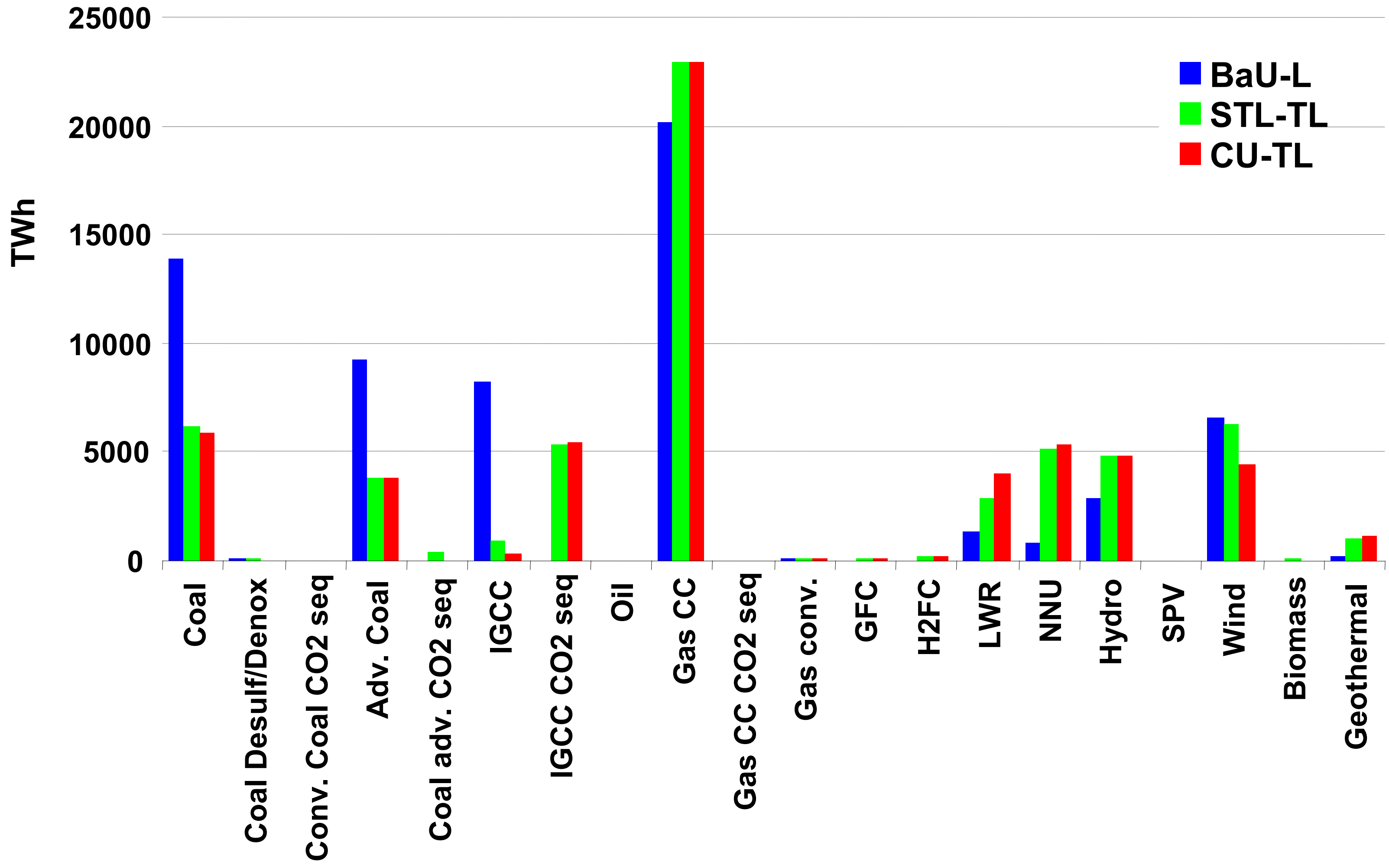


Trade in CO2 emissions permits by regions

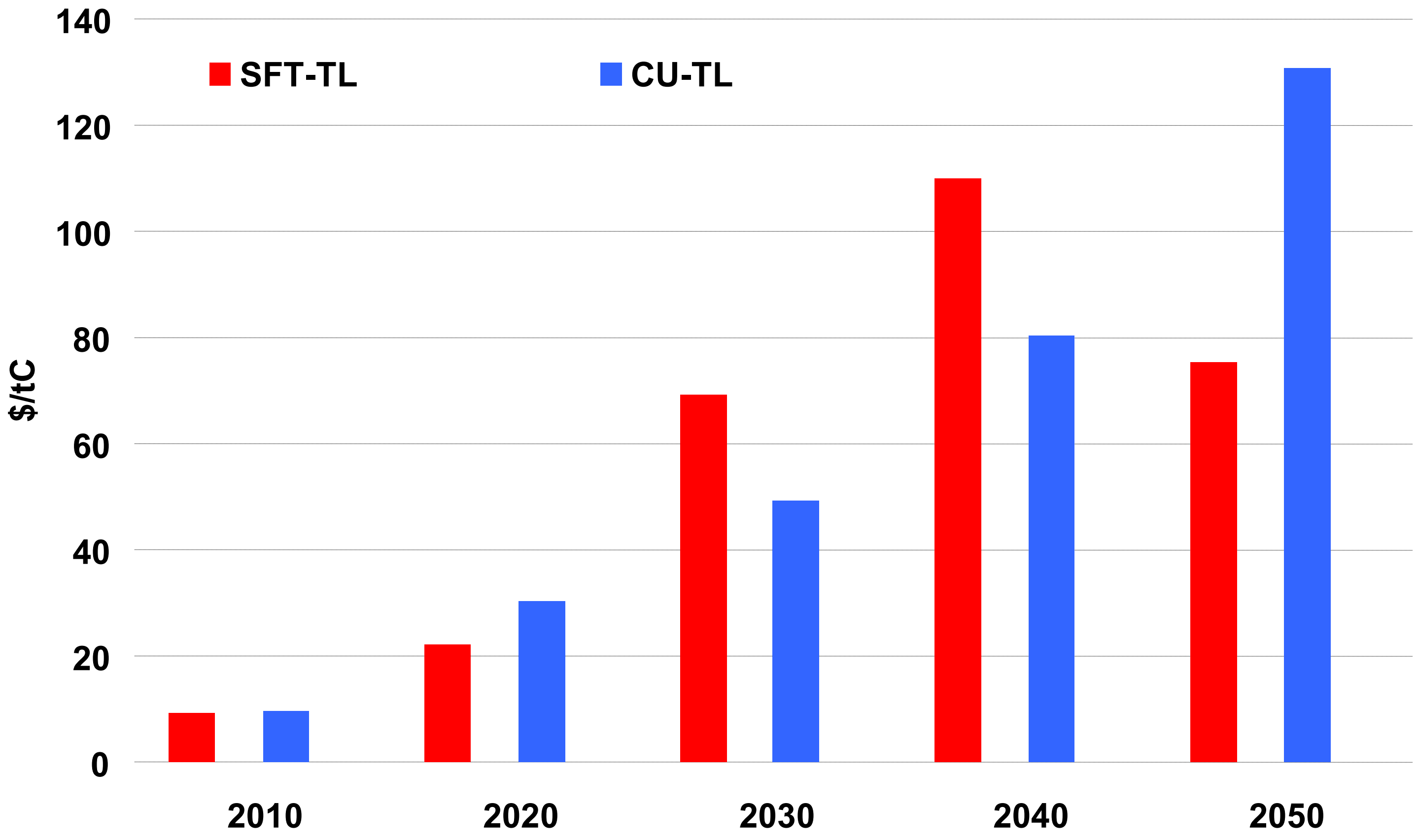




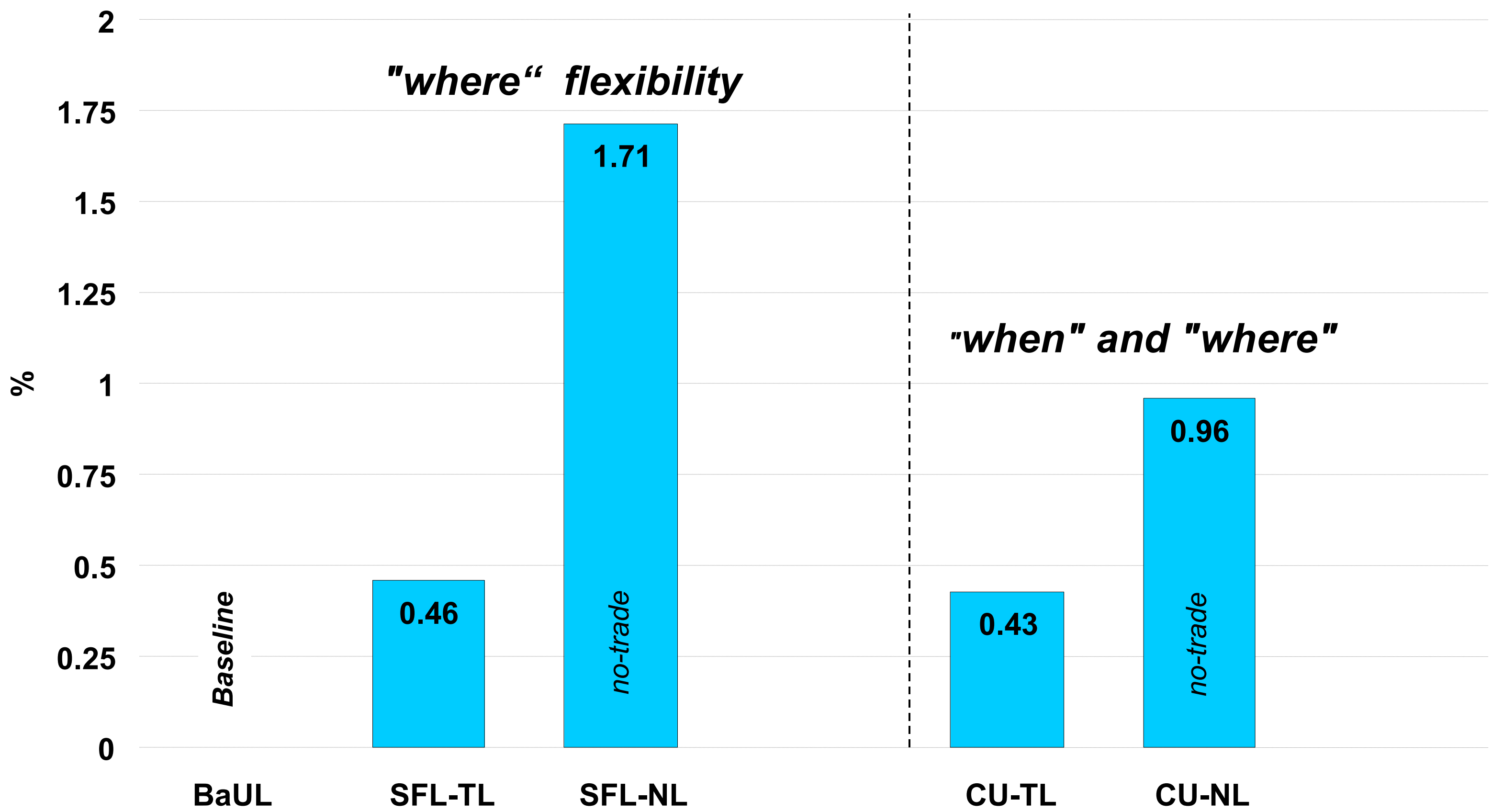
Soft – Landing; Power generation in 2050



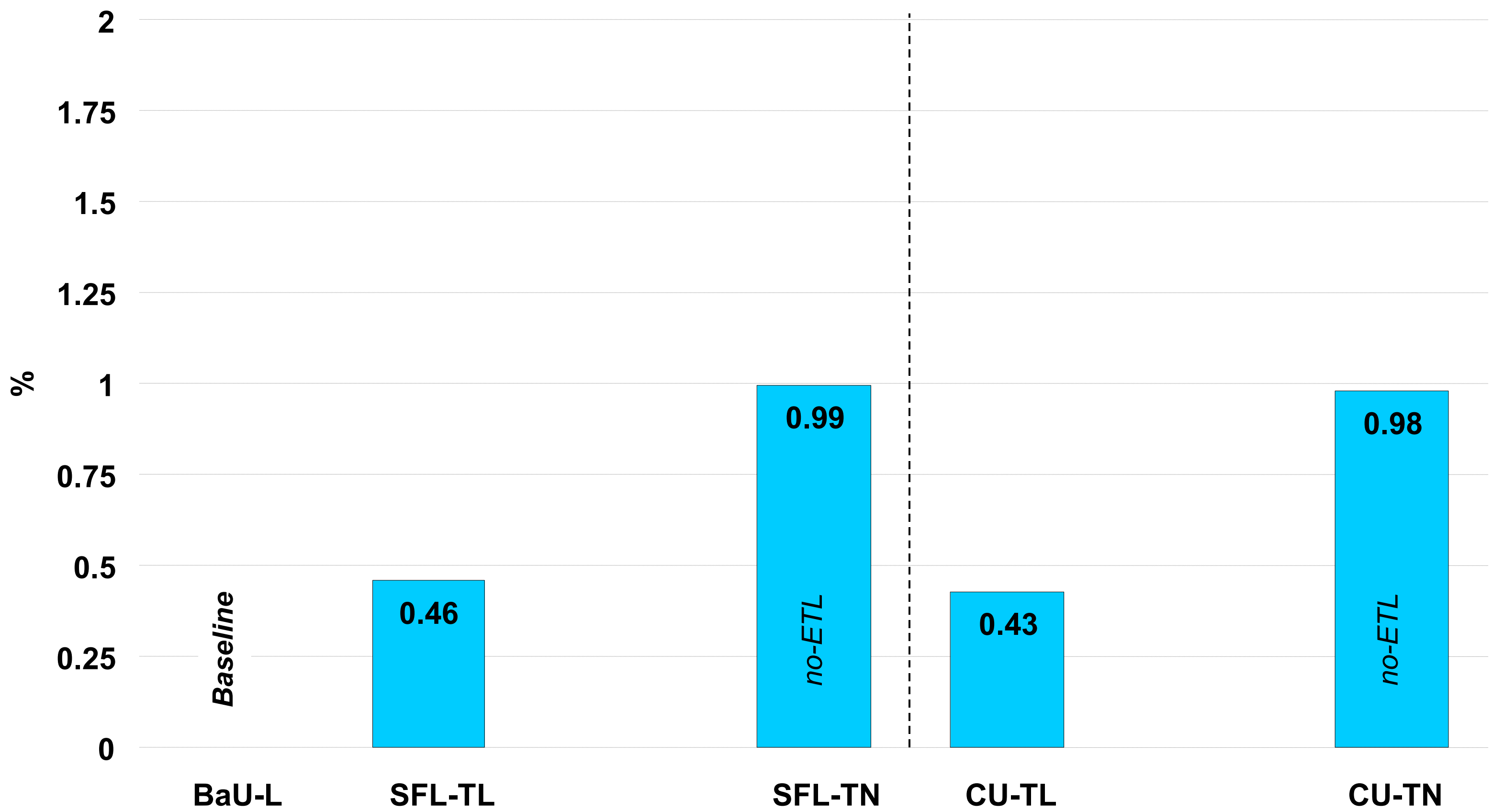
Marginal cost of Carbon Control



System Cost Change; The "when" and "where" flexibility



System Cost Change; The LBD benefits



The Externality tax Scenario

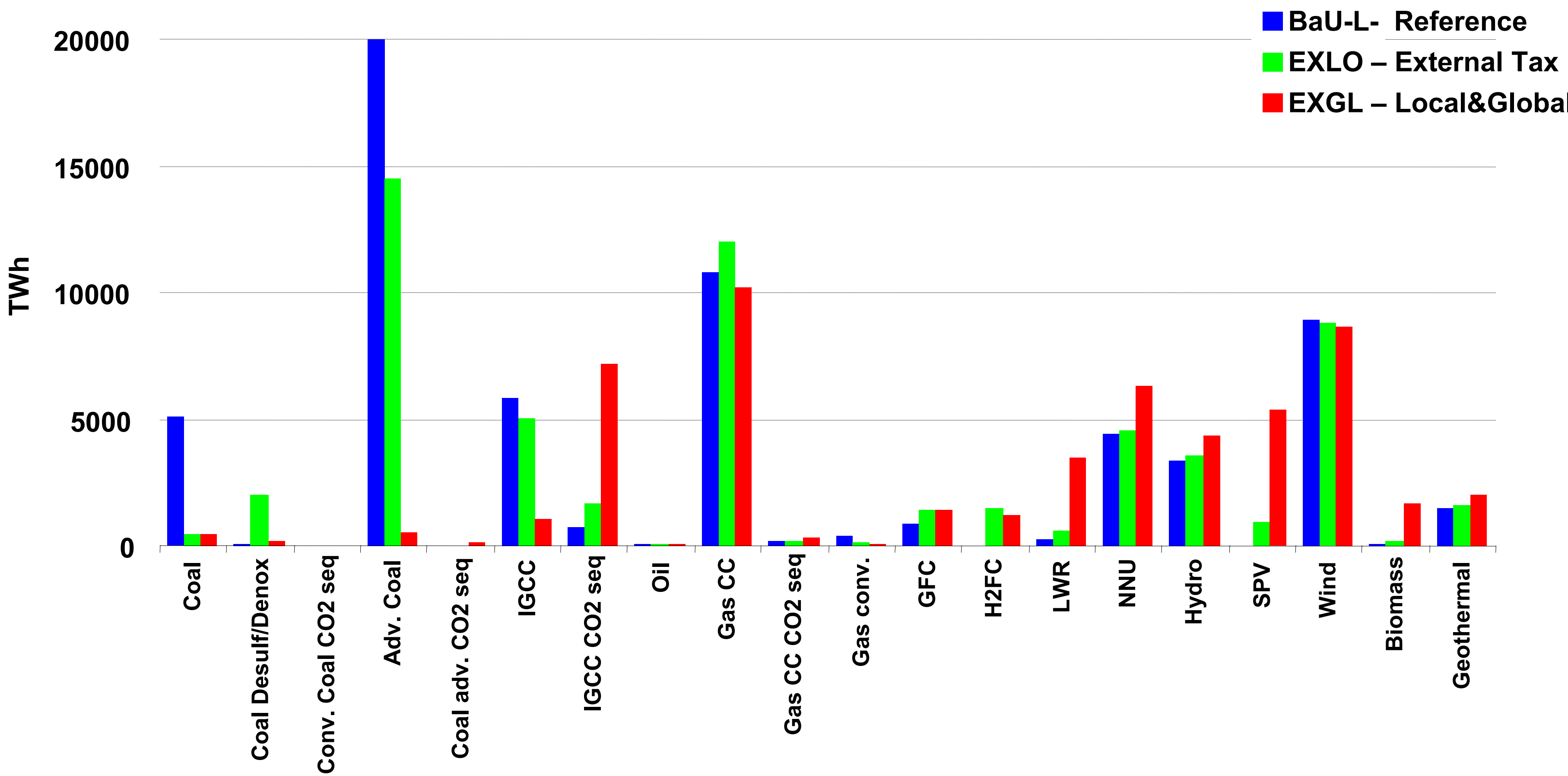
	NOX	SOX	particulates
Density: high (NL, Japan, India, China)	1.5	1.5	1.5
medium	1	1	1
low (Scandinavia,Africa)	0.75	0.75	0.5

Cost per ton of pollutant	NOX	SOX	particulates	CO2	unit
AVERAGE	7000	8000	14000	19	€/t

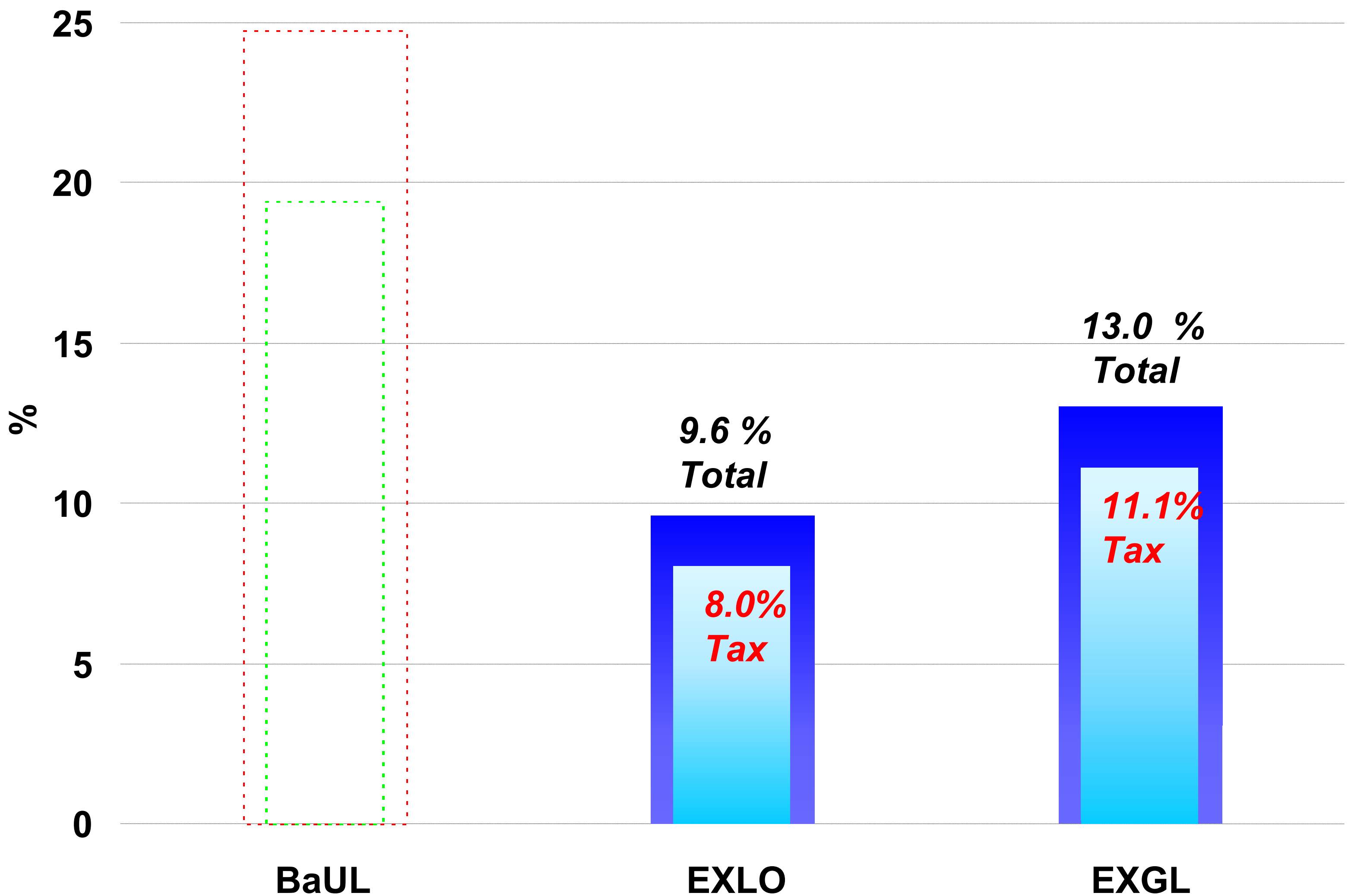
uncontrolled emissions	NOX	SOX	Particulates	CO2	
coal 1% S	4000	4000	7500	878049	kg/GWh
oil 1% S	2400	5000	20	693000	kg/GWh
gas	2000	0	0	353455	kg/GWh

	efficiency	
coal	41	%
oil	40	%
gas	55	%

Externalities;
Electricity generation by technology in 2050



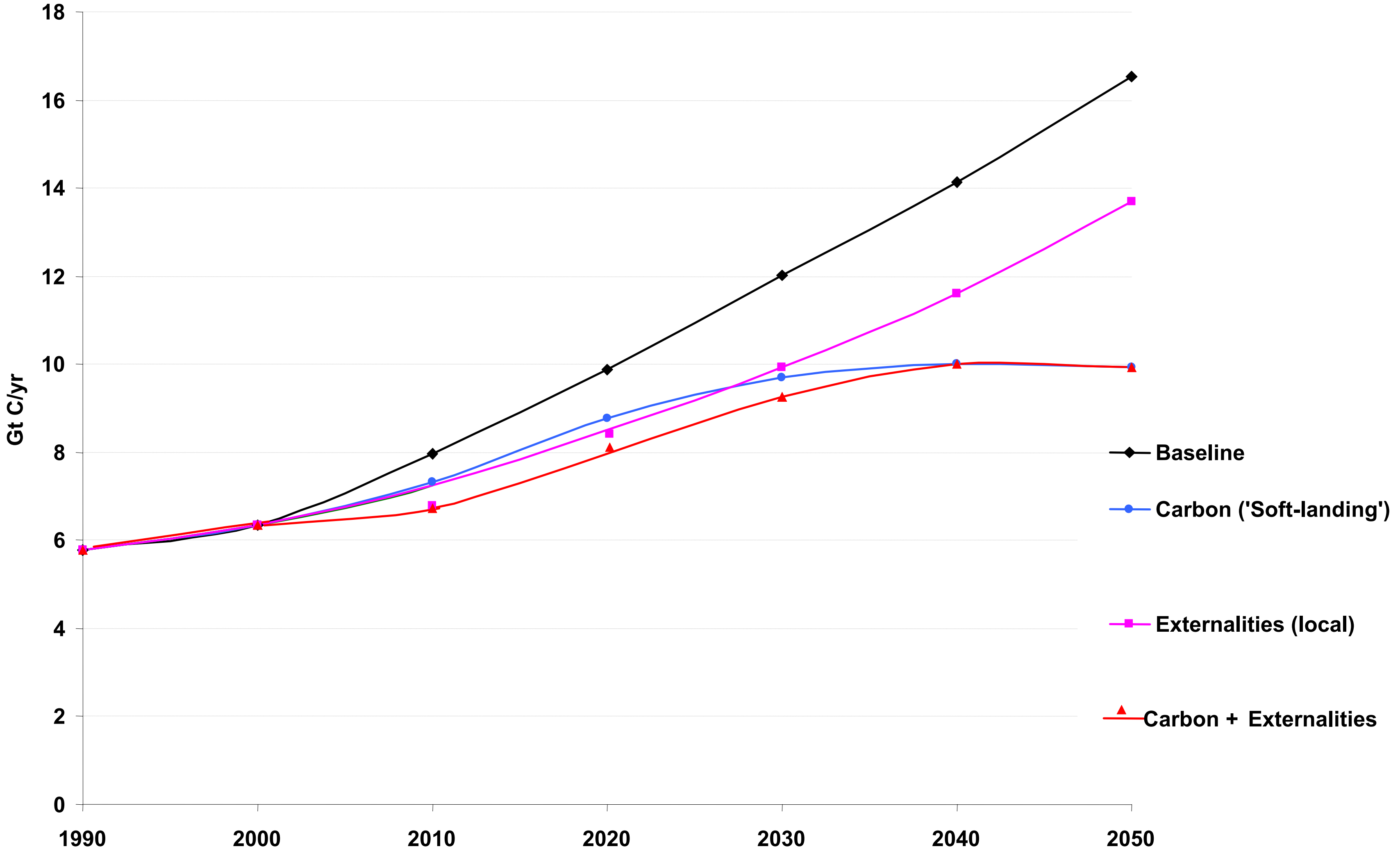
Relative change in the cumulative discounted energy system cost including local (EXLO) and local+global (EXGL) external cost



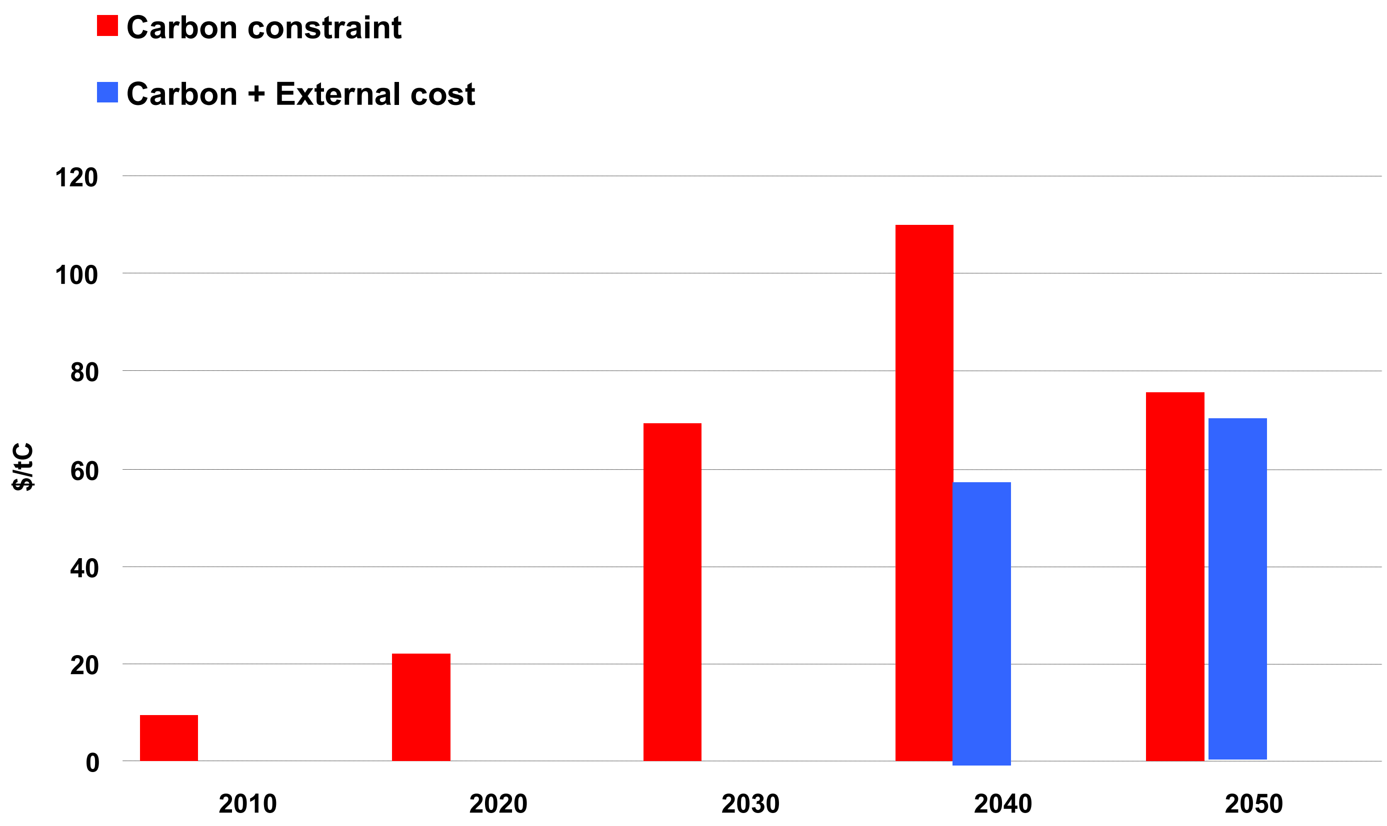
Conclusions on Externalities

- **Internalisation of externalities with or w/o climate change fosters introduction of emissions control systems and low-emitting plants**
- **Both types of external costs reduce environmental impacts**
- **Charging "global and local" externalities leads to a strong decarbonisation effect, since renewables and carbon sequestration technologies become competitive**
- **Models indicates substantial changes in the electricity production (i.e., diffusion of new technologies and fuel switching), and some efficiency loss due to the use of scrubbers (DeNOx, DeSOx, & CC)**
- **Learning-by-doing reduces external costs**

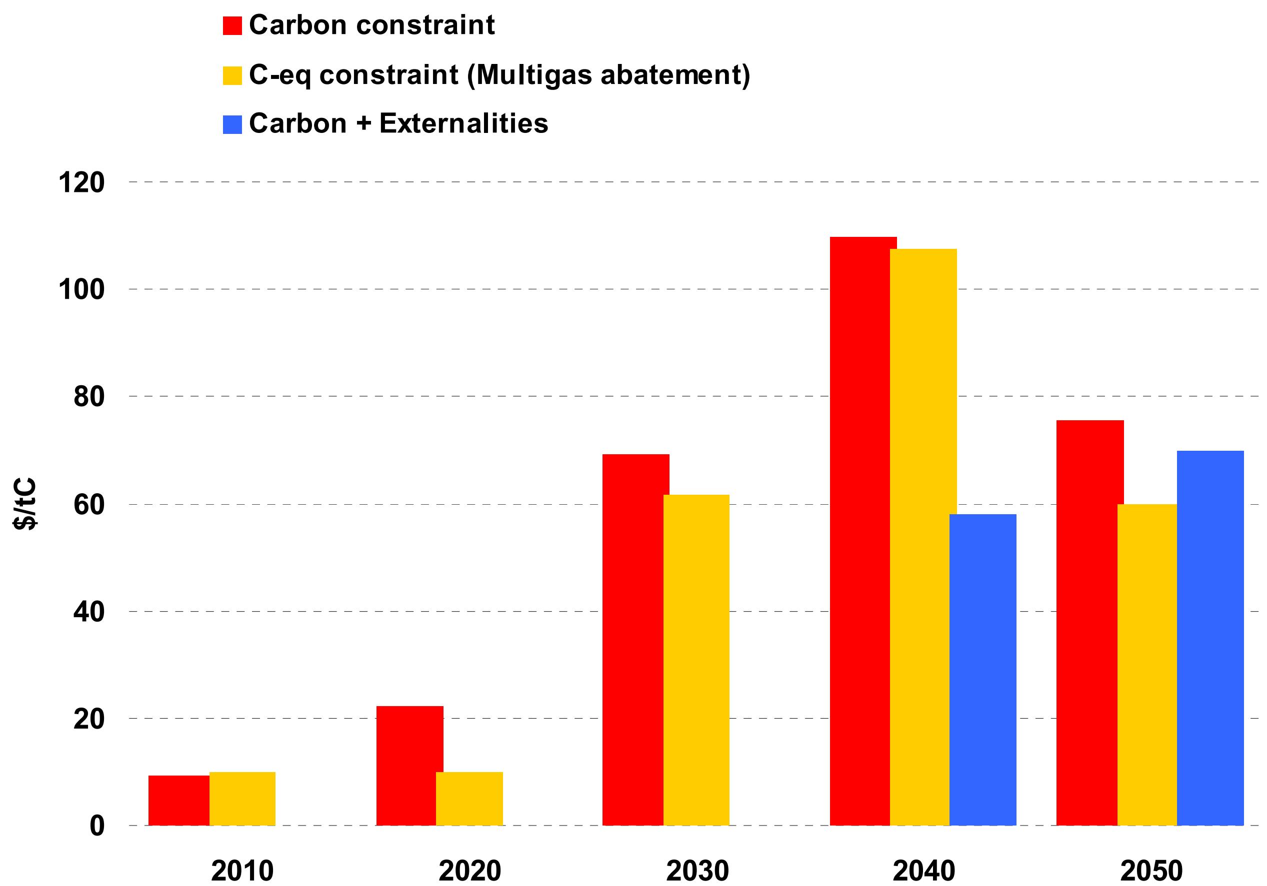
Emission paths under different scenarios



Combined Policies: Marginal Cost of Carbon Control



Marginal Cost of Carbon Control; Multi-Gas Study



Conclusions I

- ***Support of new low-carbon technologies*** **reduces the overall cost in carbon mitigation by 57% but, policies in favour of promising and non-competitive yet technologies is a prerequisite to establish them in the energy markets**

- ***Trade of emissions permits or the "Where" flexibility:*** **Cap & trade of permits identifies efficient carbon control options across the world and contributes to a significant reduction in control cost**

- ***Optimal timing or the "When" flexibility:*** **this analysis documents the need to search for optimal paths in reducing global carbon emissions.**

- **Including *all other GHGs* will reduce the carbon price as the reduction cost of CH_4 is lower to that of CO_2**

Conclusions II

- The Carbon Price can be reduced below $100 per ton of carbon in the Soft-Landing scenario (i.e., a variant of the 550-ppm case)
- The energy system cost or the GWP increase over the baseline is below 0.5% for the 550-ppmv case
- Contributing options are carbon sequestration, wind, nuclear energy, renewables (e.g., biomass) and energy efficiency measures
- Multi-gas reduction policies have economic benefits
- Significant secondary benefits should be expected when policies apply simultaneously internalising local and global externalities

Conclusions III

- **There is no a unique price of carbon (e.g., compare results of the *"Where"* , *"What"* and *"When"* flexibility or the combined policies with *externalities)***

- **Carbon free technologies need RD&D to become competitive**

- **Markets will not support this development to the extend needed, as**
  - **RD&D is a costly and long term commitment for technologies that are not yet competitive**
  - **R&D creates positive externalities via spillovers and private investors are not motivated**
  - **Local pollution creates negative externalities that are not yet addressed**
  - **Resource depletion is not fully reflected in the price of fuels**

- **Policy intervention is needed to correct for market failures**

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- **Kypreos, S. (2003), "Modeling experience curves in MERGE", (*Forthcoming*) (Energy), Presented at the IEW, IIASA-2003.**
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