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Economic Comparison of GHG Mitigation Options in Germany

ECEEE 2007 Summer Study, La Colle sur Loup

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Agenda

- Greenhouse gas mitigation options:
  1) Energy efficiency, 2) fuel switching, 3) CCS, 4) non-CO_2 GHG emissions reduction
- Options vary by time and ability to represent them in economic analysis
- Objective of paper: provide balanced analysis of these options
- Use CGE model for Germany (SGM Germany)
- Analyze costs of mitigating GHG emissions under different policy scenarios

Policy Scenarios

targeted to sectors covered by EU emissions tradings system, i.e. electric power and energy-intensive industries

CO_2 price scenarios	2000	2005	2010	2015	2020	2025+
stepwise CO_2-eq price	0	10	20	30	40	50
10 € per t CO_2-eq	0	10	10	10	10	10
20 € per t CO_2-eq	0	10	20	20	20	20
30 € per t CO_2-eq	0	10	30	30	30	30
40 € per t CO_2-eq	0	10	40	40	40	40
50 € per t CO_2-eq	0	10	50	50	50	50

Second Generation Model SGM-Germany

- Collection of computable-general-equilibrium (CGE) models for 14 world regions
- Regional model (e.g. Germany) can be run independently
- Dynamic recursive model
- Five-year time steps from 1995 through 2050
- 18 sectors, thereof 8 energy sectors

Production sectors in SGM Germany

Crude oil production
Natural gas production
Coal production

Coke and coal products
Electricity generation
- oil-fired
- gas-fired
- coal-fired
- nuclear
- hydro
- advanced technologies

Electricity distribution
Gas distribution
Oil refining

Pulp and paper
Chemicals
Non-metallic minerals
Primary metals
Food Processing
Other industry

Rail&land transport
Other transport

Agriculture

Services (everything else)

Technologies in SGM Germany

- Introduce bottom up technology information in energy economy model
- Keep richness of each set of information (macro-economic, energy, engineering)
- Focus on advanced electricity:
  - Advanced wind (offshore)
  - IGCC (integrated coal gasification comb. cycle)
  - PCA (advanced pulverized coal)
  - NGCC (natural gas combined cycle)
  - with and without CO_2 capture and storage (CCS)
- Availability:
  - IGCC, NGCC, PCA in 2015,
  - Wind and CCS technology in 2020

- Levelized costs of electricity production (COE):

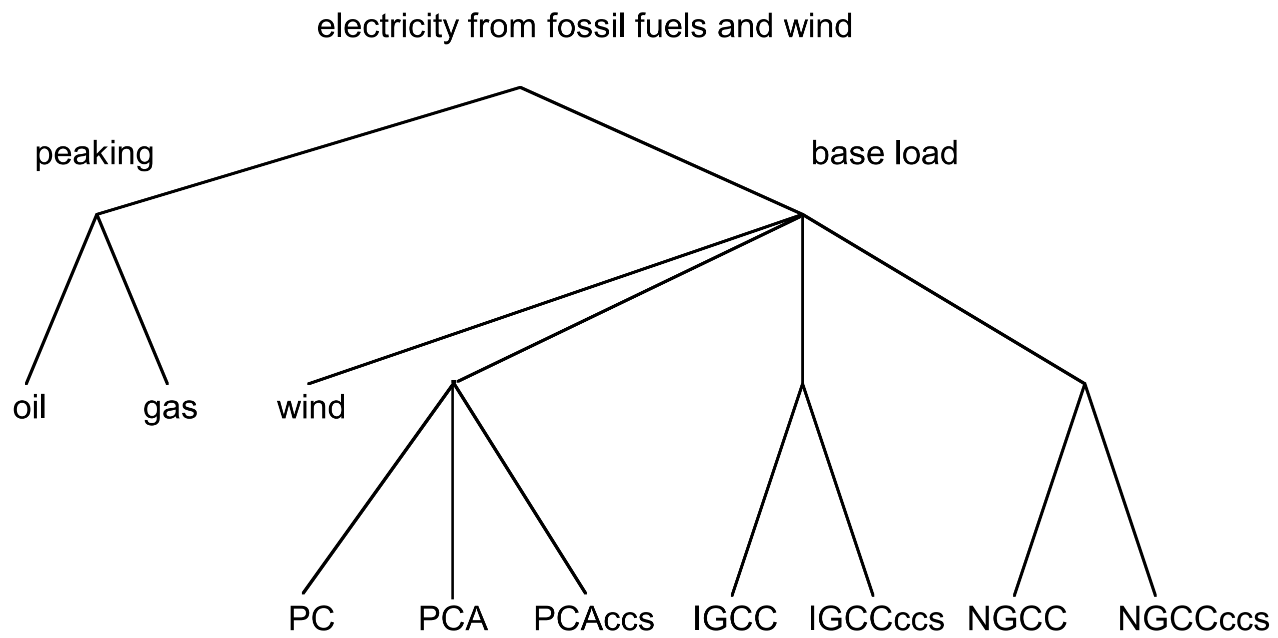
COE = capital cost + labor cost + fuel cost
+ (capture + transport/storage cost)

Engineering cost model

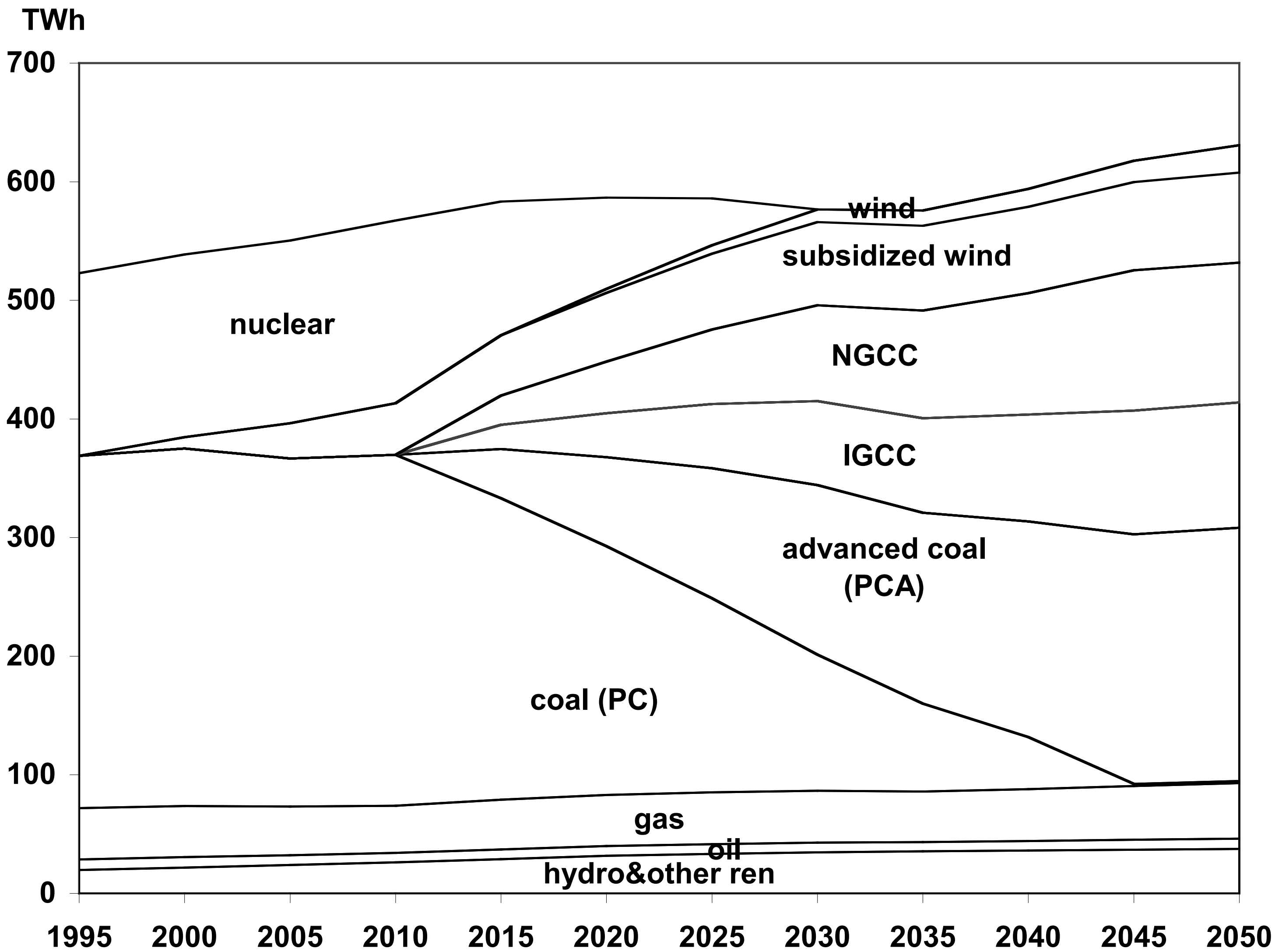
- Electricity Generation (hypothetical plant)
  - First cost of capital (€ per kW)
  - Interest rate
  - Equipment lifetime (years)
  - Heat rate (efficiency)
  - Operation and maintenance (cents per kWh)
  - Price of fuel (€ per GJ)
  - Carbon emissions coefficient (kg C per GJ)
- Capture Process
  - Fraction of CO_2 captured (efficiency)
  - Capital Cost (€ per kg CO_2 per hour)
  - Operation and Maintenance (cents per kg CO_2)
  - Energy required (kWh per kg CO_2)
- Calculate total cost per kWh with and without capture for each generating technology

Electricity sector in SGM Germany

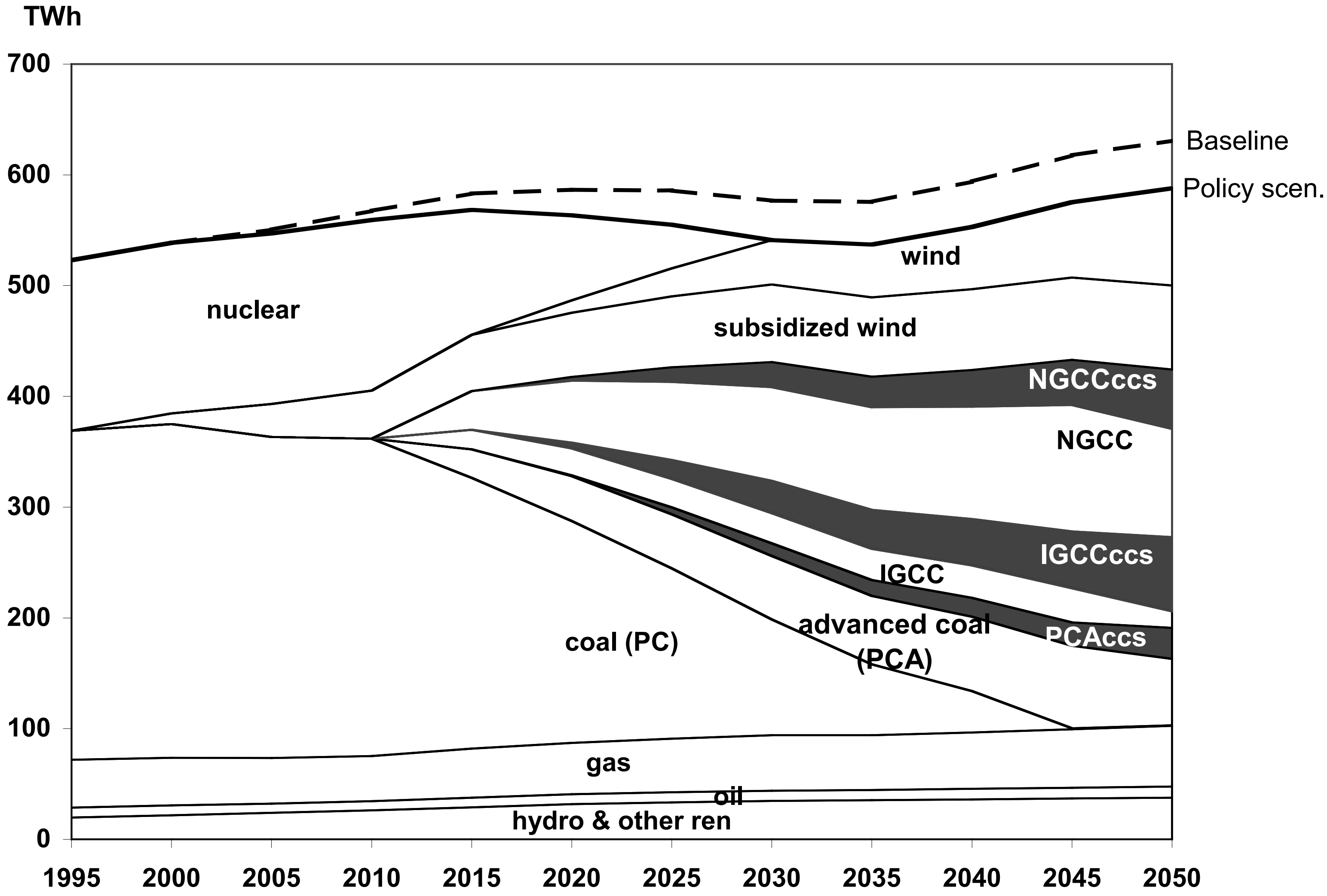
- All production sectors other than electricity represented by single CES production function
- Each electric generating technology represented by fixed-coefficient production function
- Electricity sector uses a nested logit structure to allocate new investment to generating technologies



SGM Results: Baseline electricity generation



Electricity sector results – stepwise policy case



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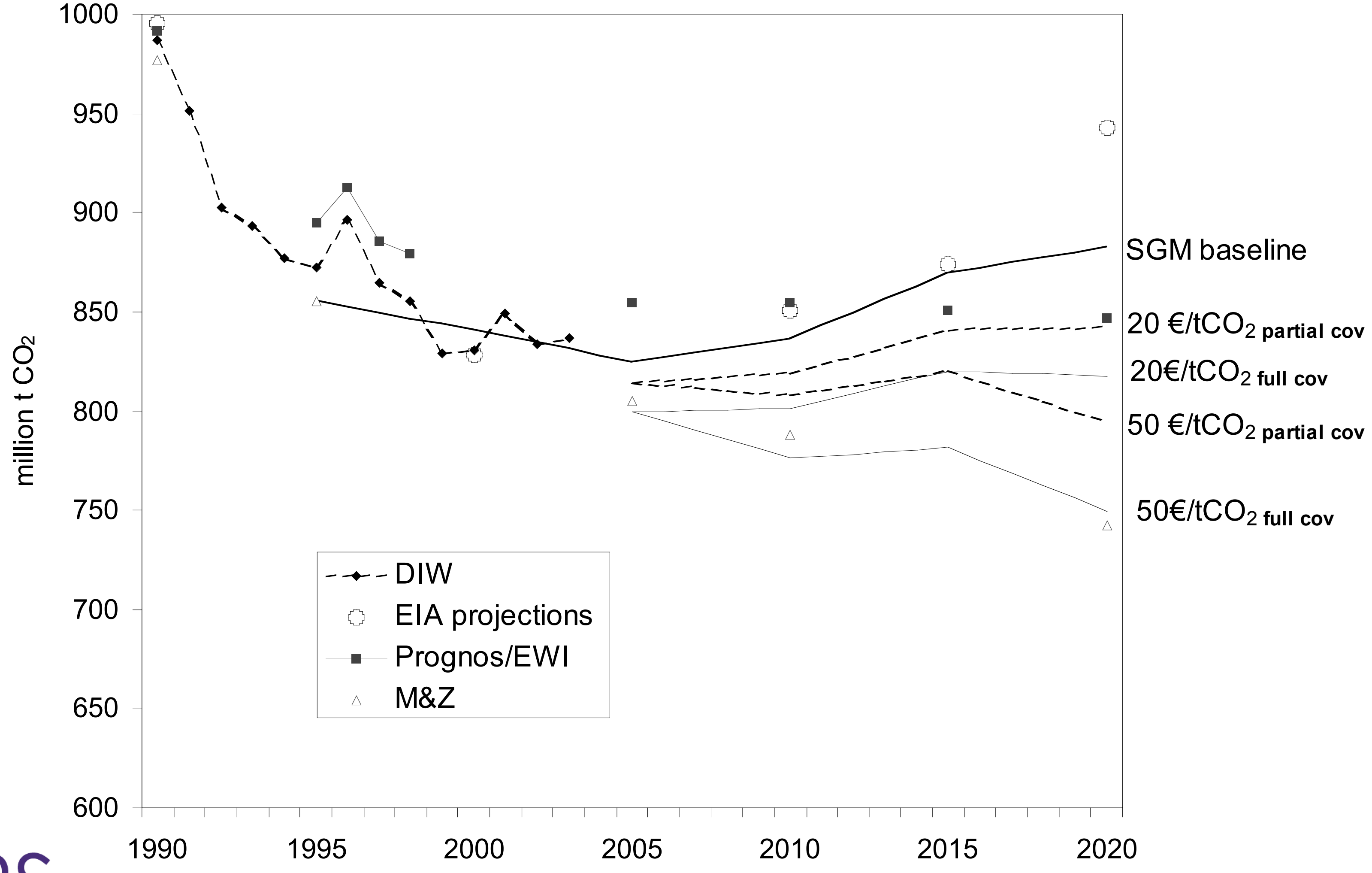
CO_2 emissions in SGM Germany



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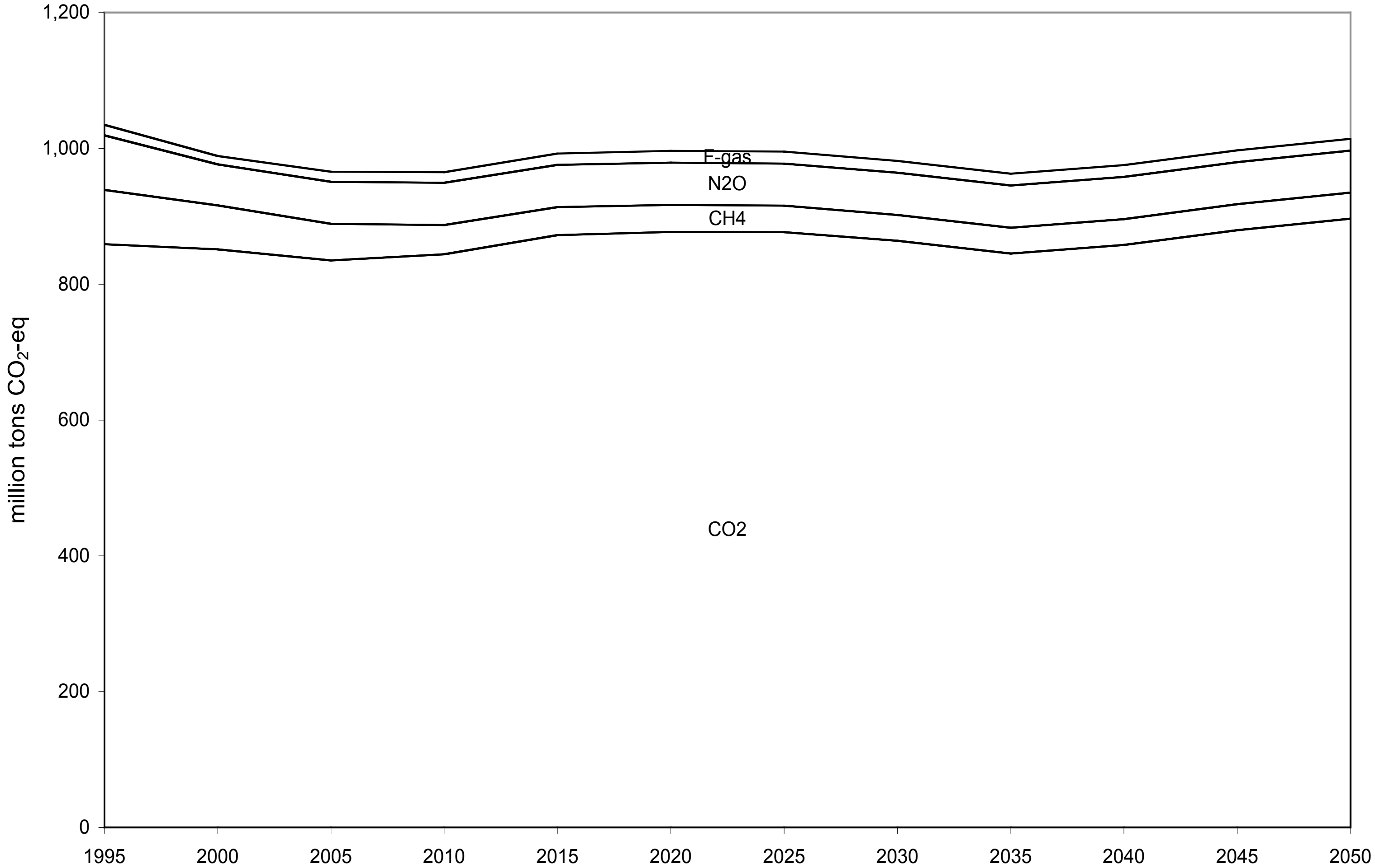
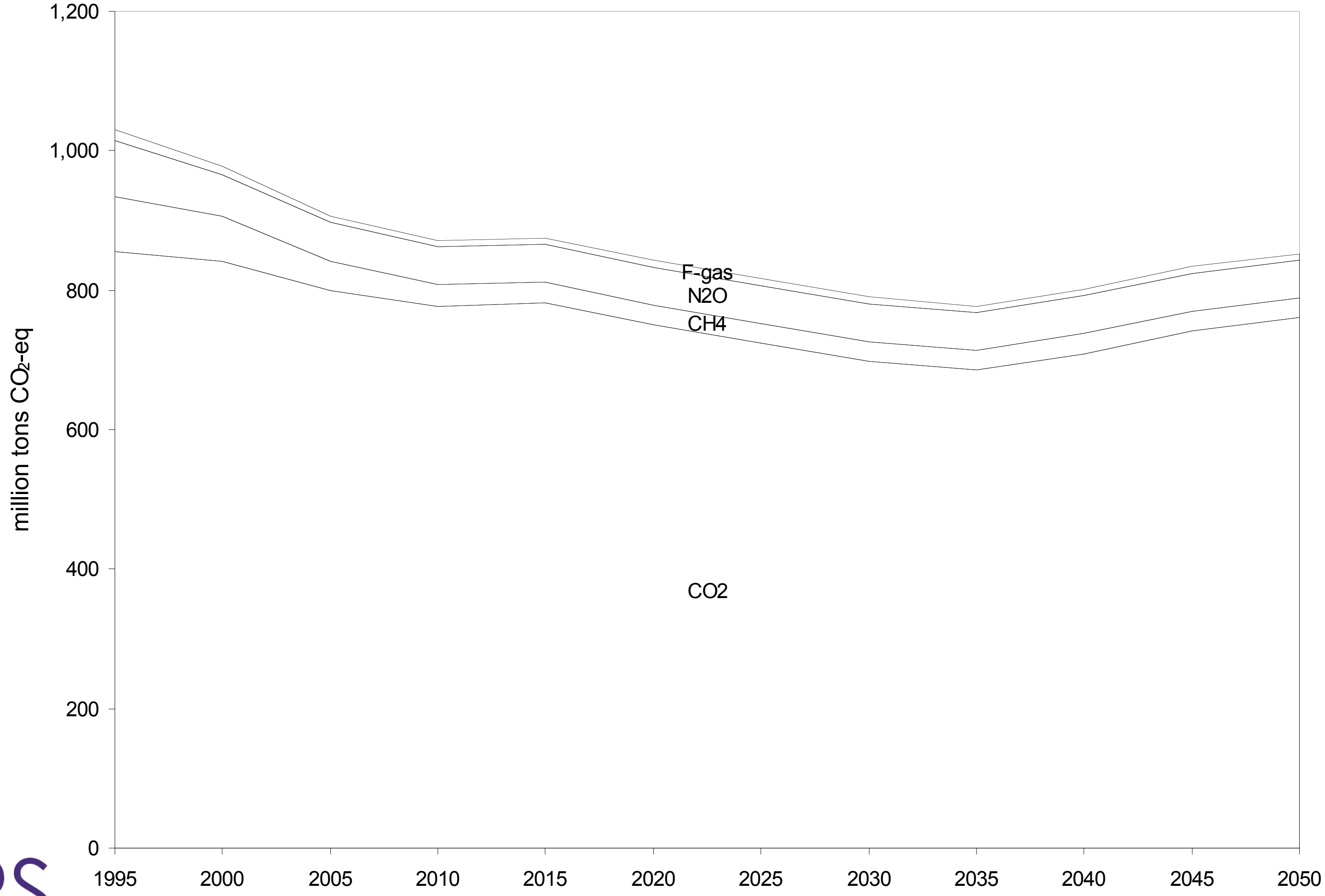
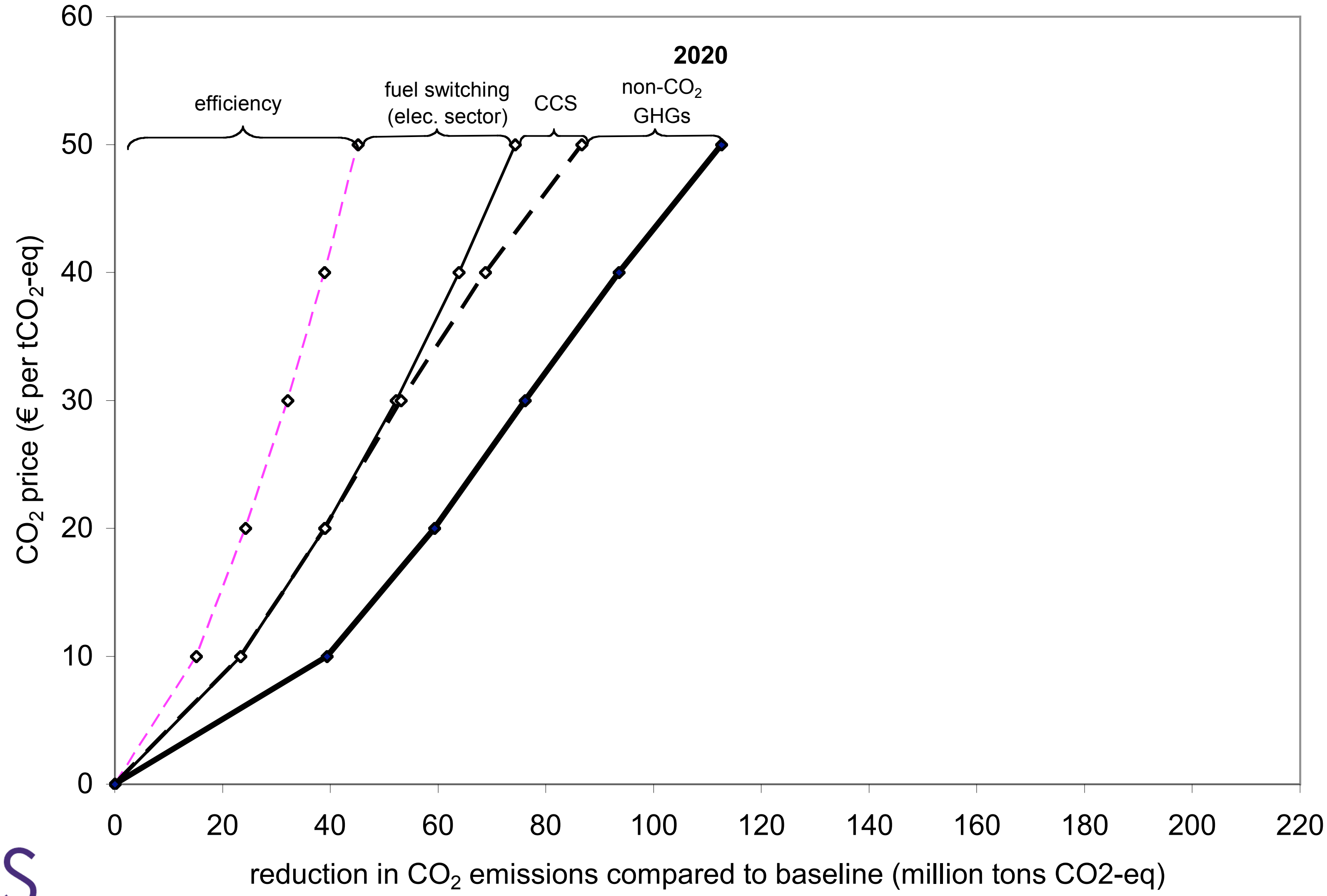
GHG emissions pathway baseline



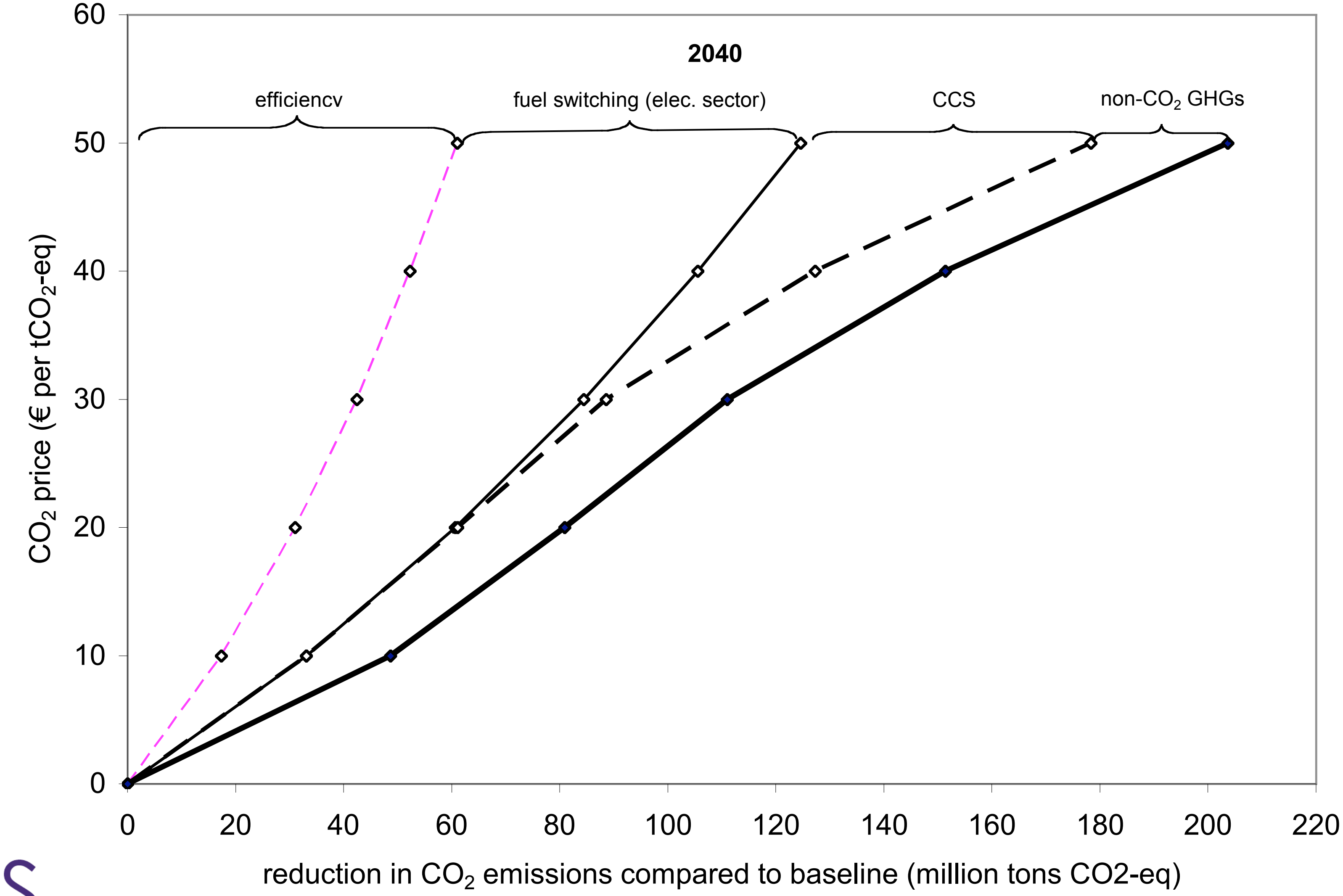
GHG emissions pathway 50€/t CO_2- eq



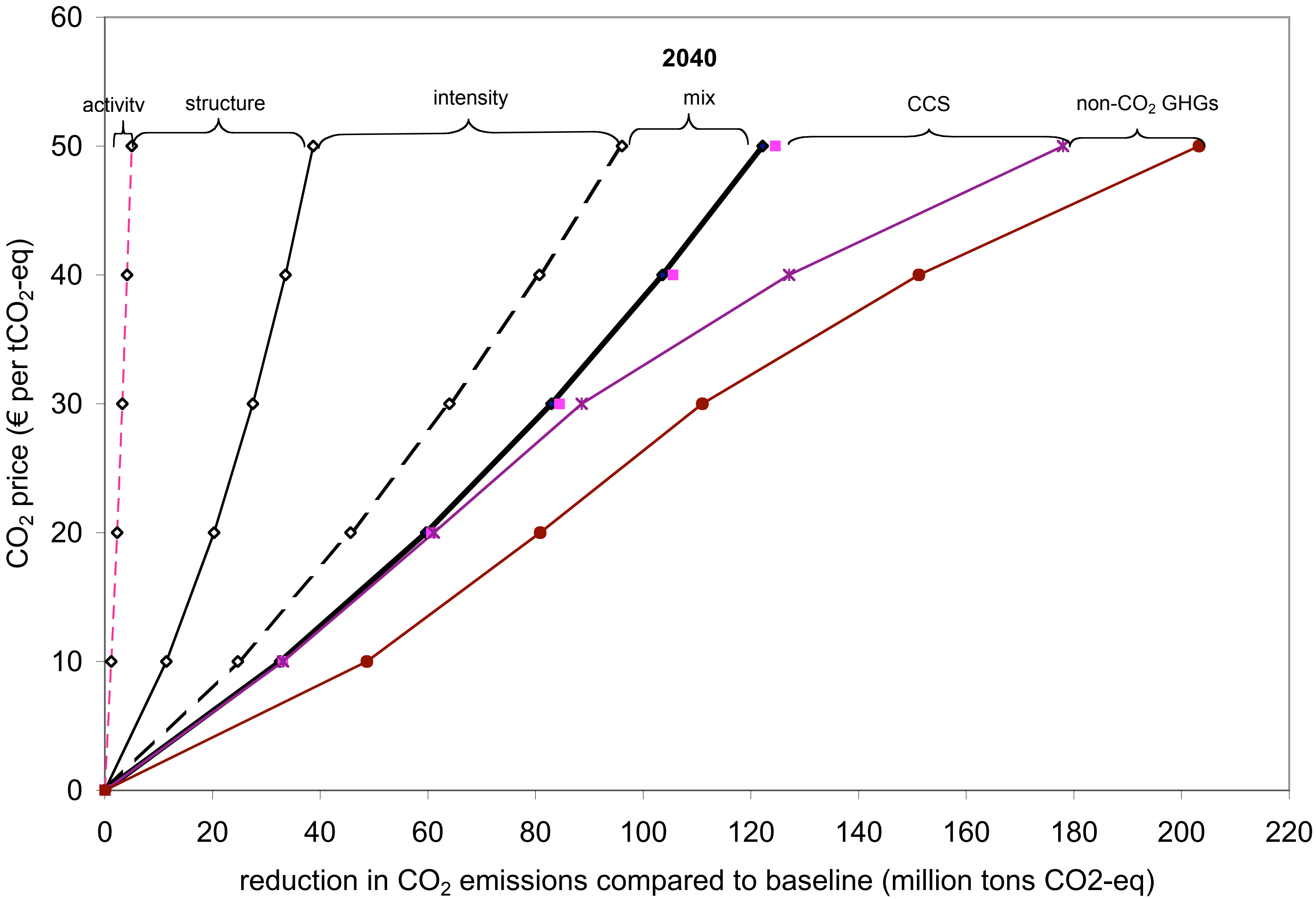
Economic comparison of mitigation options 2020



Economic comparison 2040



Economic comparison 2040



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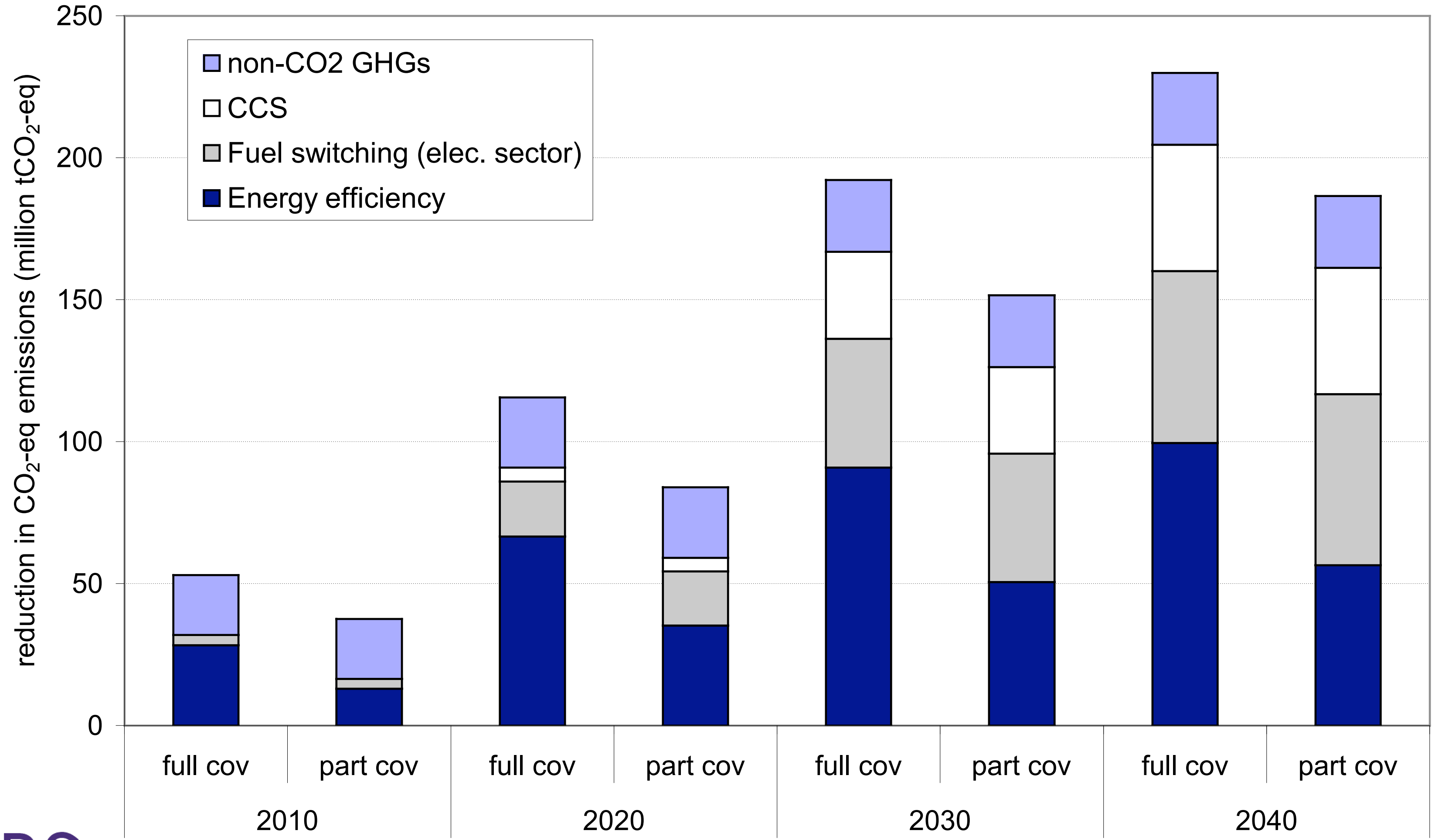
Decomposition of emissions reductions, stepwise CO_2 price, full and partial coverage



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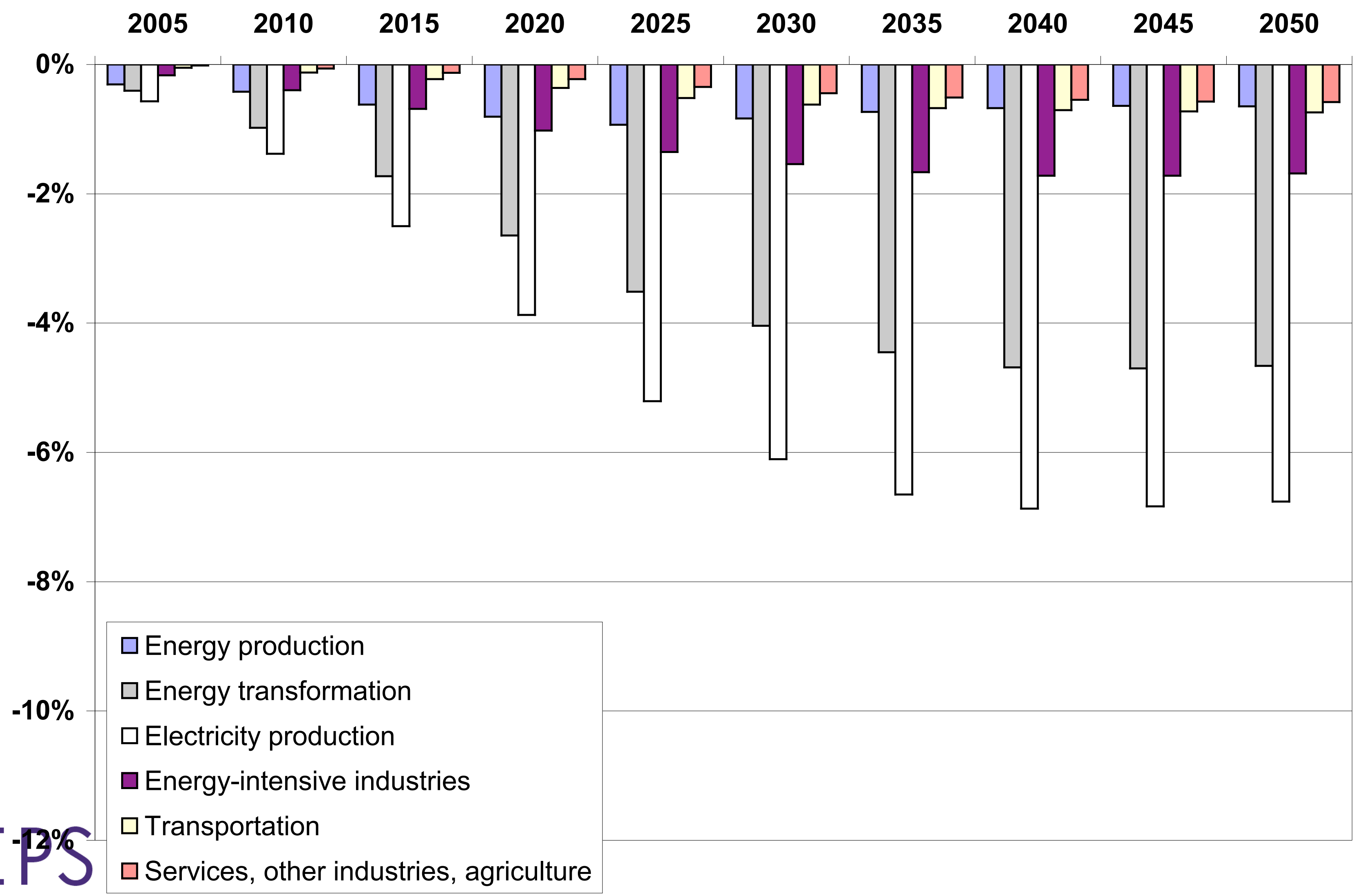
Change in sectoral output, stepwise CO_2 price



Conclusions

- One step toward providing more realistic scenarios of greenhouse gas mitigation options in Germany
- End-of-pipe character of non-CO_2 greenhouse gas mitigation options means that they can be deployed relatively quickly on both new and existing capital equipment.
- Rate that other greenhouse gas mitigation options can deploy is generally limited by the rate that existing capital stocks retire
- Limitation: Model only accounts for price signals (direct/indirect), not for other policies & measures
- Future work: More refined decomposition of the energy efficiency component into production (energy) efficiency and output shift components

Thank you

Your comments are welcome!

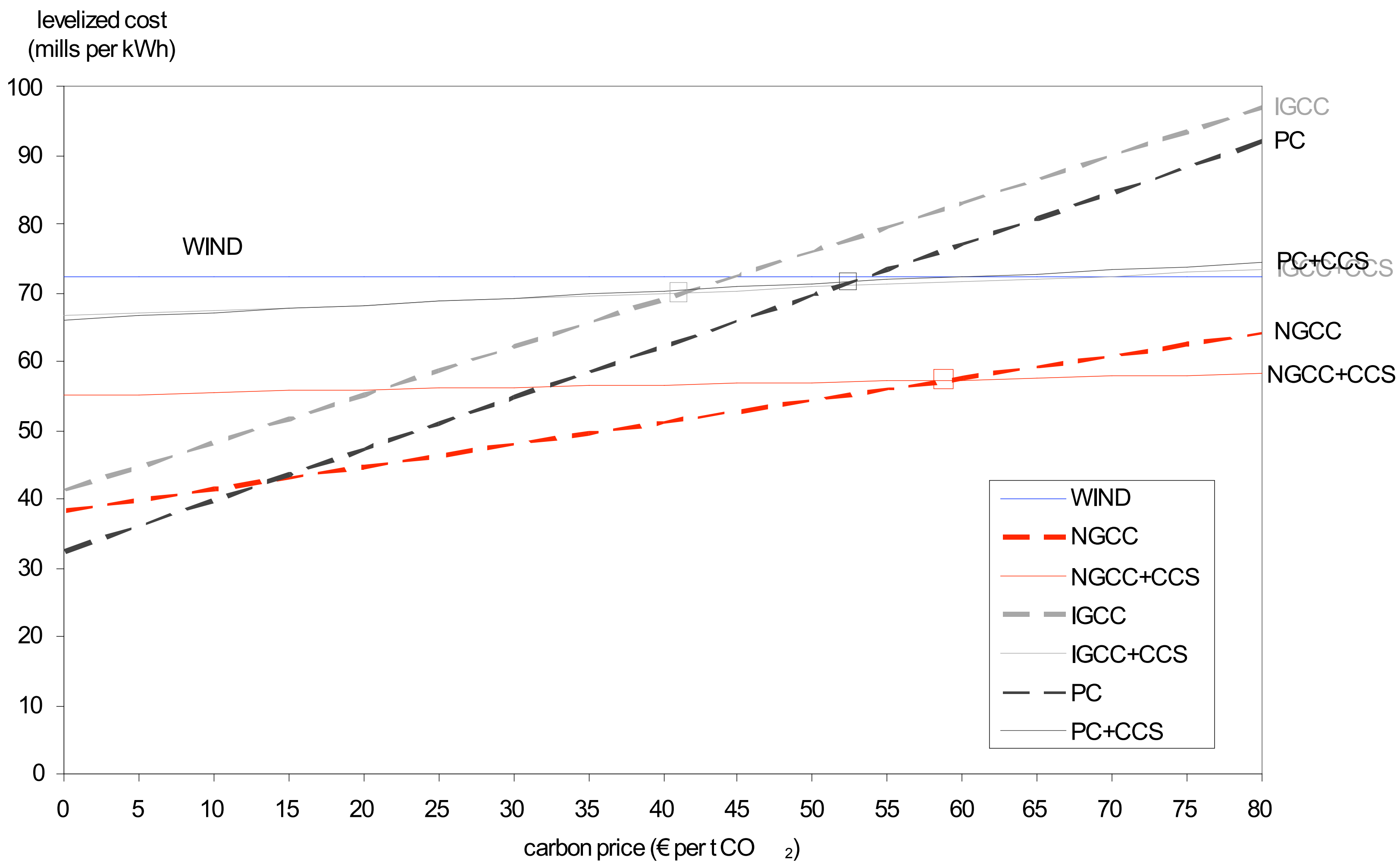
Cost and Performance Measures	Wind	PC Plant			IGCC Plant			NGCC Plant		
	Ikarus	Enquete	David/ Herzog	IEA	Enquete	David/ Herzog	IEA	Enquete	David/ Herzog	IEA
without CCS										
Conversion Efficiency (%)		51%	42%	43%	54%	48%	46%	62%	60%	56%
Plant Factor (%)	36%	75%	75%	75%	75%	75%	75%	75%	75%	75%
Emn. Rate (kg CO_2/kWh)		0.629	0.756	0.746	0.594	0.671	0.697	0.294	0.301	0.323
Capital cost (cent/kWh)	5.71	1.28	1.29	1.26	1.72	1.40	1.78	0.54	0.64	0.49
Labor cost (cent/kWh)	1.52	0.80	0.61	0.52	1.55	0.61	0.98	0.39	0.24	0.33
Fuel cost (cent/kWh)		1.24	1.49	1.47	1.17	1.32	1.38	2.76	2.82	3.03
COE (cent/kWh)	**7.23**	**3.32**	**3.39**	**3.26**	**4.44**	**3.34**	**4.14**	**3.69**	**3.70**	**3.84**
with CCS										
Conversion Efficiency (%)			36%	31%	48%	43%	38%		55%	47%
Emn. Rate (kg CO_2/kWh)			0.089	0.103	0.067	0.074	0.084		0.033	0.038
Investment cost (Euro/kW)			1708	1850	2033	1462	2100		850	800
Capital cost (cent/kWh)			2.01	2.17	2.49	1.79	2.58		1.04	0.98
Labor cost (cent/kWh)			1.16	1.39	2.07	0.85	1.59		0.42	0.55
Fuel cost (cent/kWh)			1.66	2.04	1.32	1.38	1.67		3.22	3.61
Storage cost (cent/kWh)			0.87	1.02	0.66	0.72	0.83		0.32	0.38
COE (cent/kWh)			**5.70**	**6.62**	**6.54**	**4.75**	**6.66**		**5.01**	**5.51**
Cost penalty (cent/kWh)			2.31	3.36	2.10	1.41	2.52		1.31	1.67
Difference in emissions (kg CO_2/kWh)			0.67	0.64	0.53	0.60	0.61		0.27	0.28
Cost of CO_2 avoided (€/t CO2)			35	52	40	24	41		49	59

Assuming 7% interest rate, 2010 fuel prices (4.71€/GJ gas, 1.76 €/GJ coal)

Treatment of Capital in SGM

- All capital stock is industry-specific
- All capital is constructed in five-year vintages
- Short-run and long-run behavior
- Technical change over time
- Capital lifetime 30 years
  - for electricity: 35 years, wind 20 years, nuclear phase out

Crossover price for electricity technologies



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Assuming 7% interest rate, 2010 fuel prices (4.71€/GJ gas, 1.76 €/GJ coal)

CES approach

CES production function

$$q(\mathbf{x}) = \alpha_0 \left[\sum_{i=1}^{N} (\alpha_i x_i)^{\rho} \right]^{1/\rho} \quad \text{with} \quad \sigma = 1/(1-\rho)$$

–The corresponding CES cost function is

$$g(\mathbf{p}) = \frac{1}{\alpha_0} \left[\sum_{i=1}^{N} \left(\frac{p_i}{\alpha_i} \right)^{r} \right]^{1/r} \quad \text{where } r = \rho/(\rho-1) \quad \text{or} \quad \sigma = 1 - r$$

pi is an element of the price vector p. The physical input-output coefficients are functions of prices and technical coefficients

$$\mathrm{a}_{ij}(\mathbf{p}) = \alpha_{0j}^{\sigma-1} \alpha_{ij}^{\sigma-1} \left[\frac{p_j}{p_i} \right]^{\sigma}$$

Technology-based approach

Leontief (fixed coefficient) unit cost function

$$C_j = \frac{1}{\acute{a}_{0j}} \sum_{i=1}^{n} \frac{p_i}{\alpha_{ij}}$$

$\sigma = 0$, C_i = levelized cost per ton of crude steel

Output share (s_j) provided by each technology according to

$$s_j = \frac{b_j C_j^{\lambda}}{\sum_k b_k C_k^{\lambda}}$$

where bj is calibration parameter to match base year production, and lambda determines rate that technologies can substitute for another.

Cost function for electricity generation using logit nest

$$g(\mathbf{p}) = \sum_j s_j C_j$$

GHG emissions sources

Gas	Source #	Emissions Source
CO_2	1	Oil combustion
	2	Gas combustion
	3	Coal combustion
CH_4	4	Coal production
	5	Enteric fermentation
	6	Natural gas and oil systems
	7	Solid waste
N_2O	8	Agricultural soil
	9	Industrial processes
	10	Manure
	11	Fossil fuels
	12	Waste
	13	Solvent use and other product use
HFCs	14	Ozone depleting substances substitutes
PFCs	15	Aluminum
	16	Semiconductor
SF_6	17	Electricity distribution
	18	Magnesium

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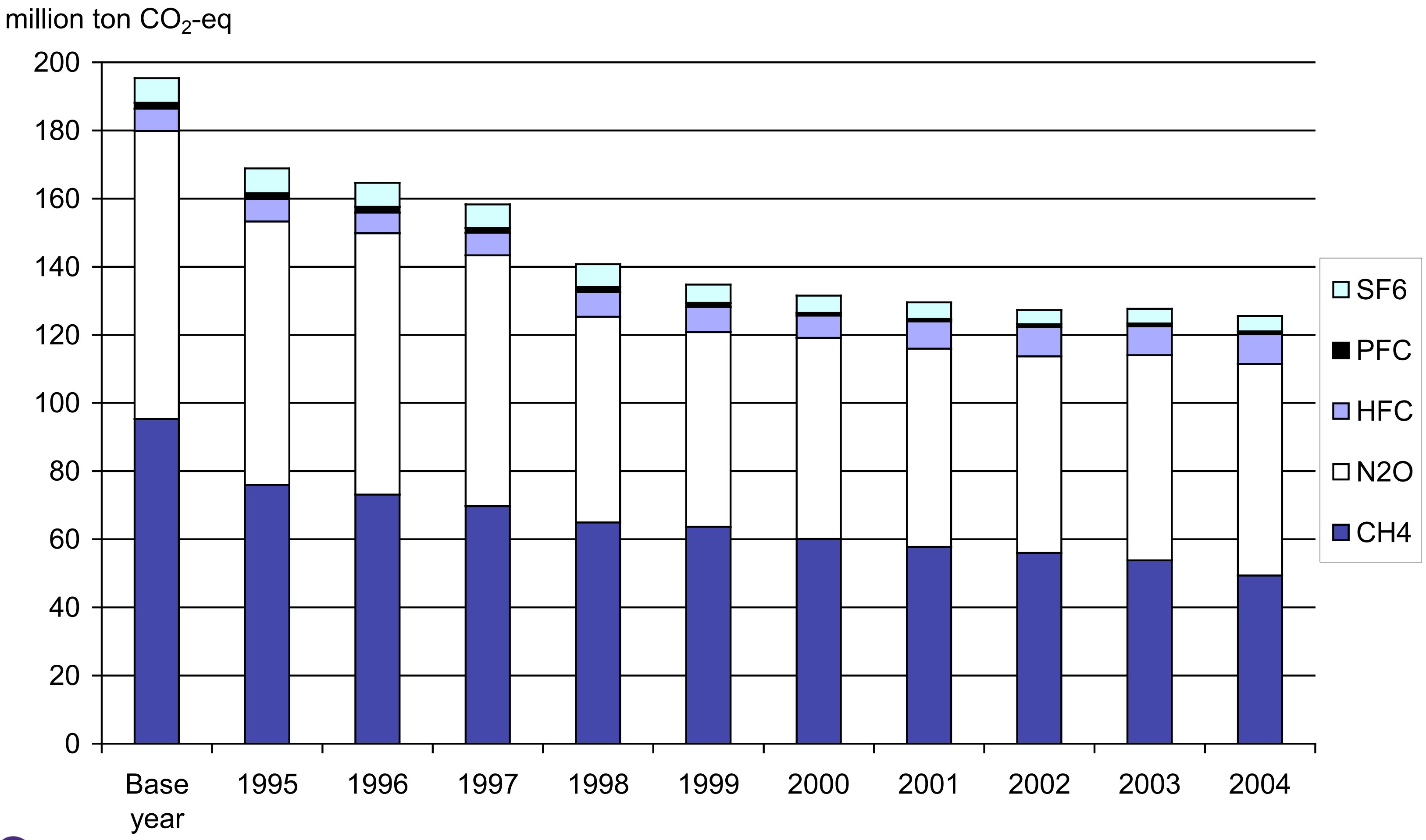
Background: Non-CO_2 GHG in Germany 1995-2004



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