Decomposition Analysis and Climate Policy in a General Equilibrium Model of Germany

Ron Sands
USA

Katja Schumacher
Germany

14th AIM International Workshop
Tsukuba, Japan
15-16 February 2009

Acknowledgments

- This presentation is a summary of the following journal article published in February 2009:
  - Sands, R.D., and K. Schumacher. (2009). “Economic comparison of greenhouse gas mitigation options in Germany,” *Energy Efficiency* **2**:17-36.
- This paper was completed while the first author was employed at Pacific Northwest National Laboratory and the second author at the Institute for Applied Ecology in Berlin.
- This work was funded in part by the German Ministry for Education and Research (BMBF) within its socio-ecological research framework and also, in part, by the US Environmental Protection Agency. The views expressed by the authors do not necessarily reflect the views of the Institute for Applied Ecology (Öko-Institut e.V.), the German Government, Pacific Northwest National Laboratory, the US Government, or any agency thereof.

Introduction

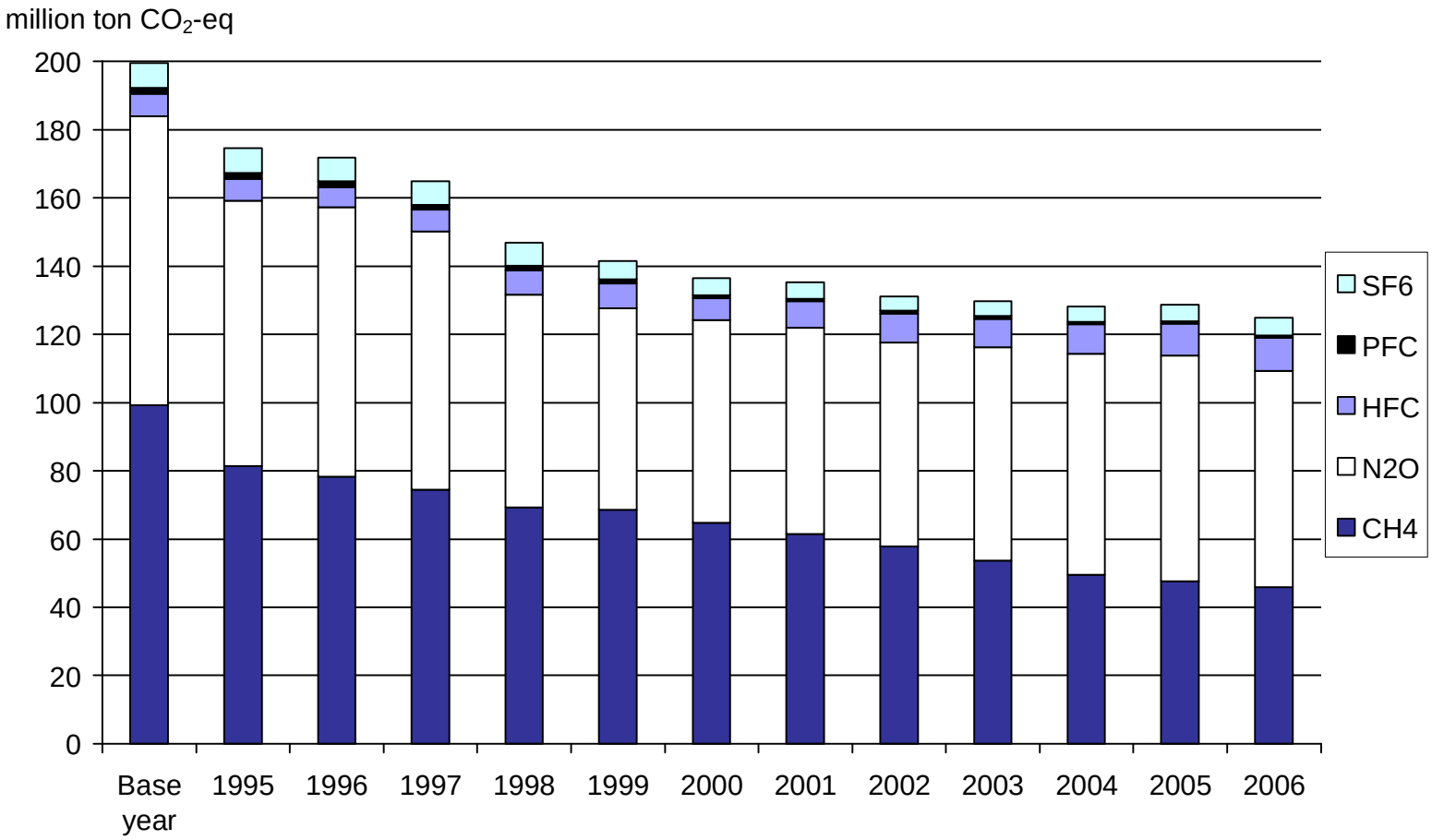
- Greenhouse gas mitigation options
  - Non-CO_2 GHG emissions reduction
  - Energy efficiency
  - Fuel switching
  - Carbon dioxide capture and storage (CCS)
- Options vary by time and ability to represent them in economic analysis
- Objective of paper
  - provide balanced analysis of these options
  - present results using a formal decomposition methodology
- 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

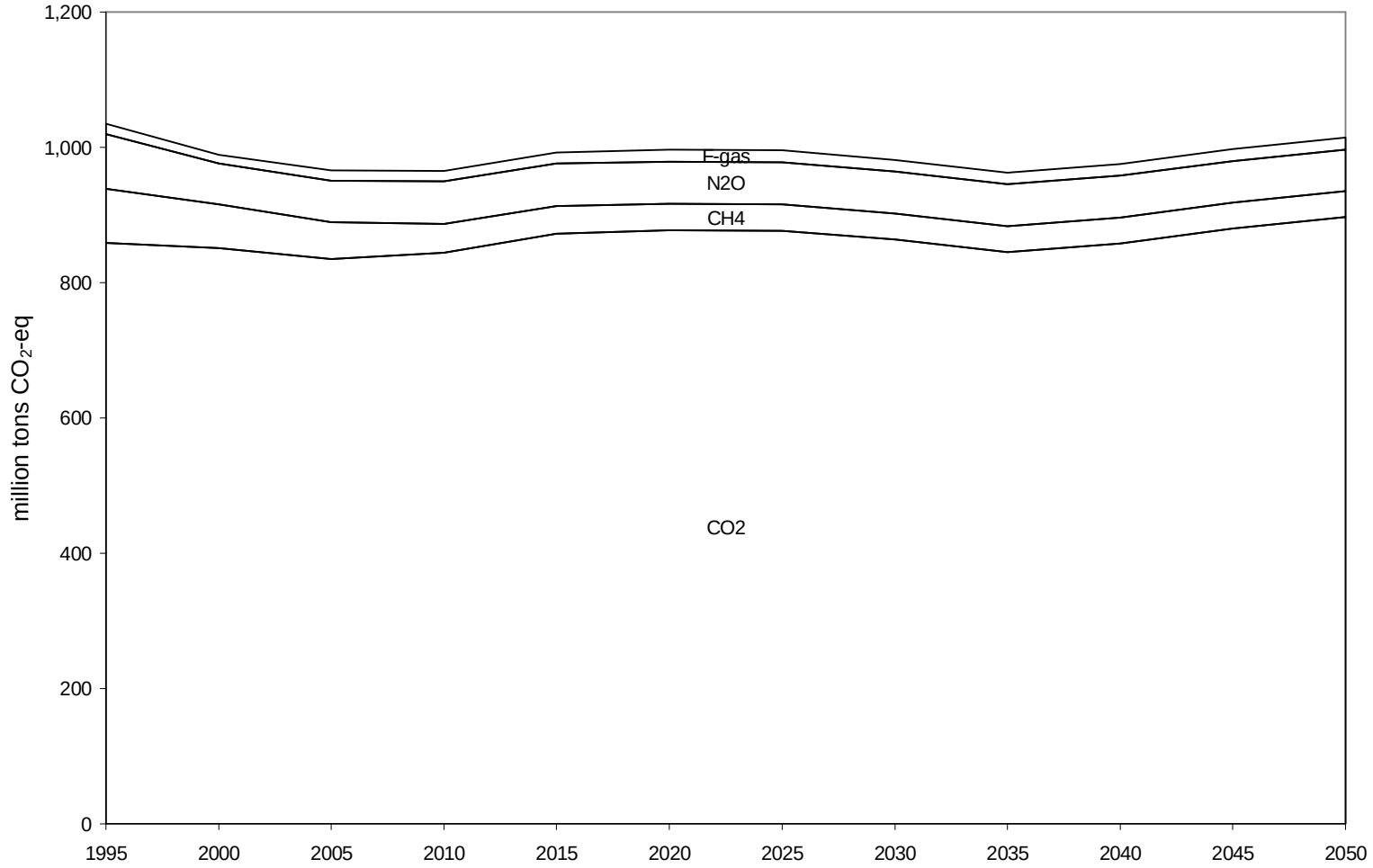
CO_2 price scenarios	**2000**	**2005**	**2010**	**2015**	**2020**	**2025+**
Stepwise CO_2-eq price	0	10	20	30	40	50
10 € per t CO_2-eq	0	10	10	10	10	10
20 € per t CO_2-eq	0	10	20	20	20	20
30 € per t CO_2-eq	0	10	30	30	30	30
40 € per t CO_2-eq	0	10	40	40	40	40
50 € per t CO_2-eq	0	10	50	50	50	50

Non-CO_2 greenhouse gas emissions in Germany, 1995-2006

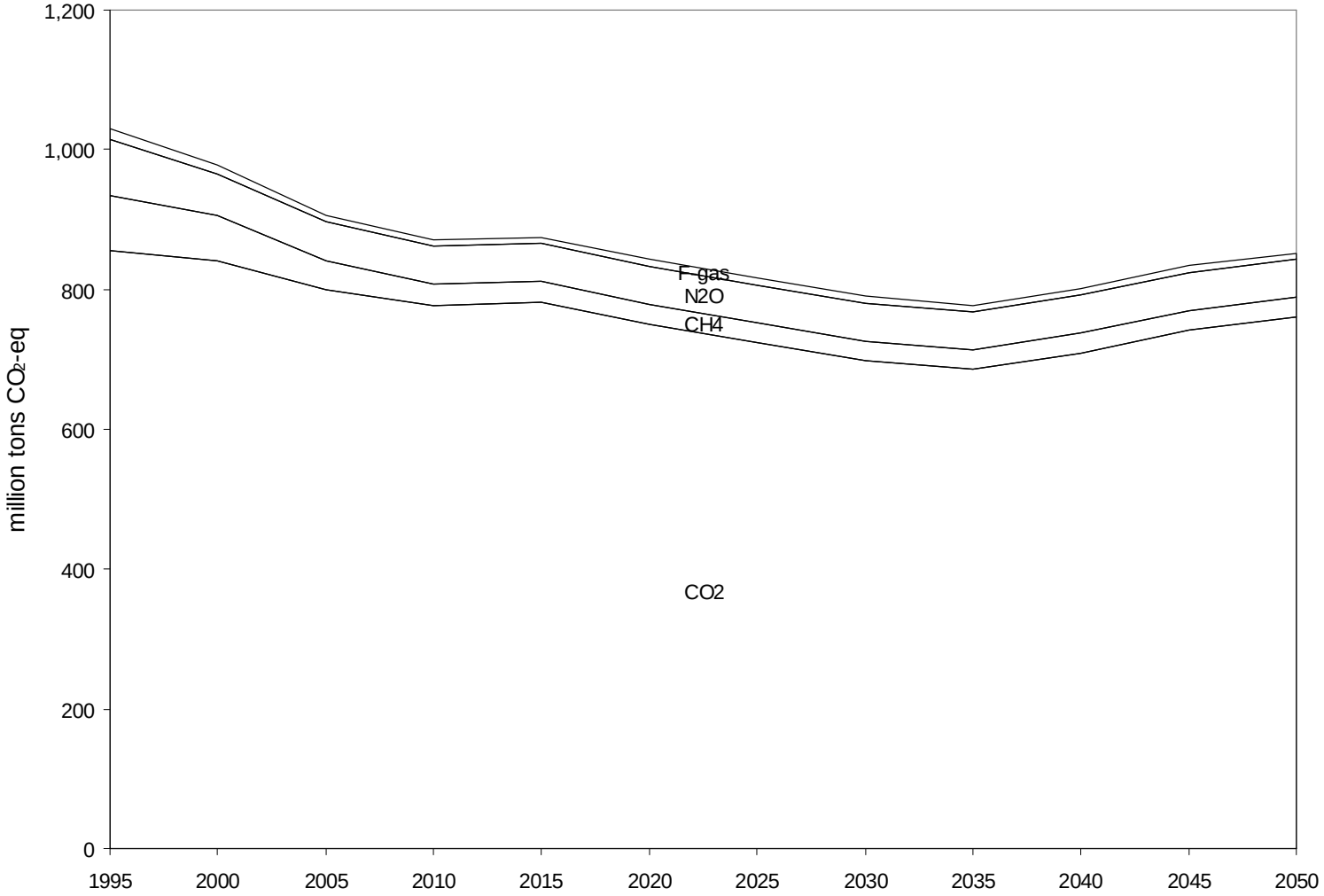


Gas	Source #	Emissions Source
CO_2	1	Oil combustion
	2	Gas combustion
	3	Coal combustion
CH_4	4	Coal production
	5	Enteric fermentation
	6	Natural gas and oil systems
	7	Solid waste
N_2O	8	Agricultural soil
	9	Industrial processes
	10	Manure
	11	Fossil fuels
	12	Waste
	13	Solvent use and other product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

GHG emissions baseline



GHG emissions pathway: 50€/t CO_2-eq



Second Generation Model

- Collection of computable-general-equilibrium (CGE) models for 14 world regions
- Regional models (e.g., Germany) can be run independently
- Dynamic recursive model
- Five-year time steps from 1995 through 2050
- 18 sectors, including 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 and land transport
- Other transport
- Agriculture
- Services (everything else)

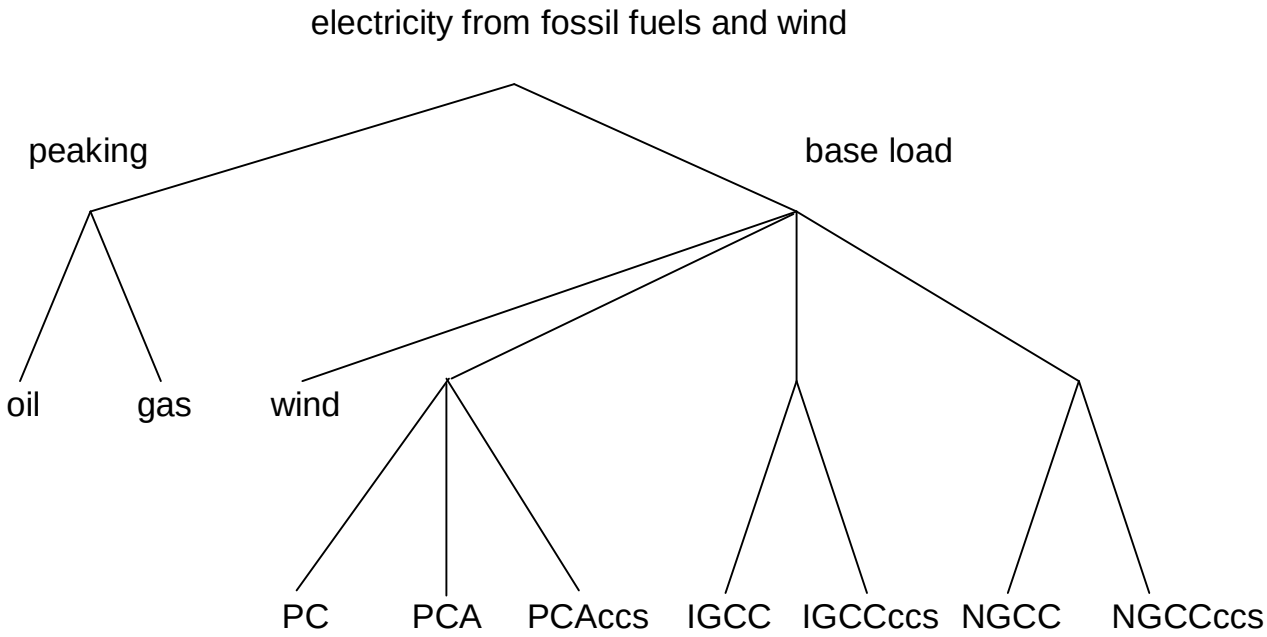
Technologies in SGM-Germany

- 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):

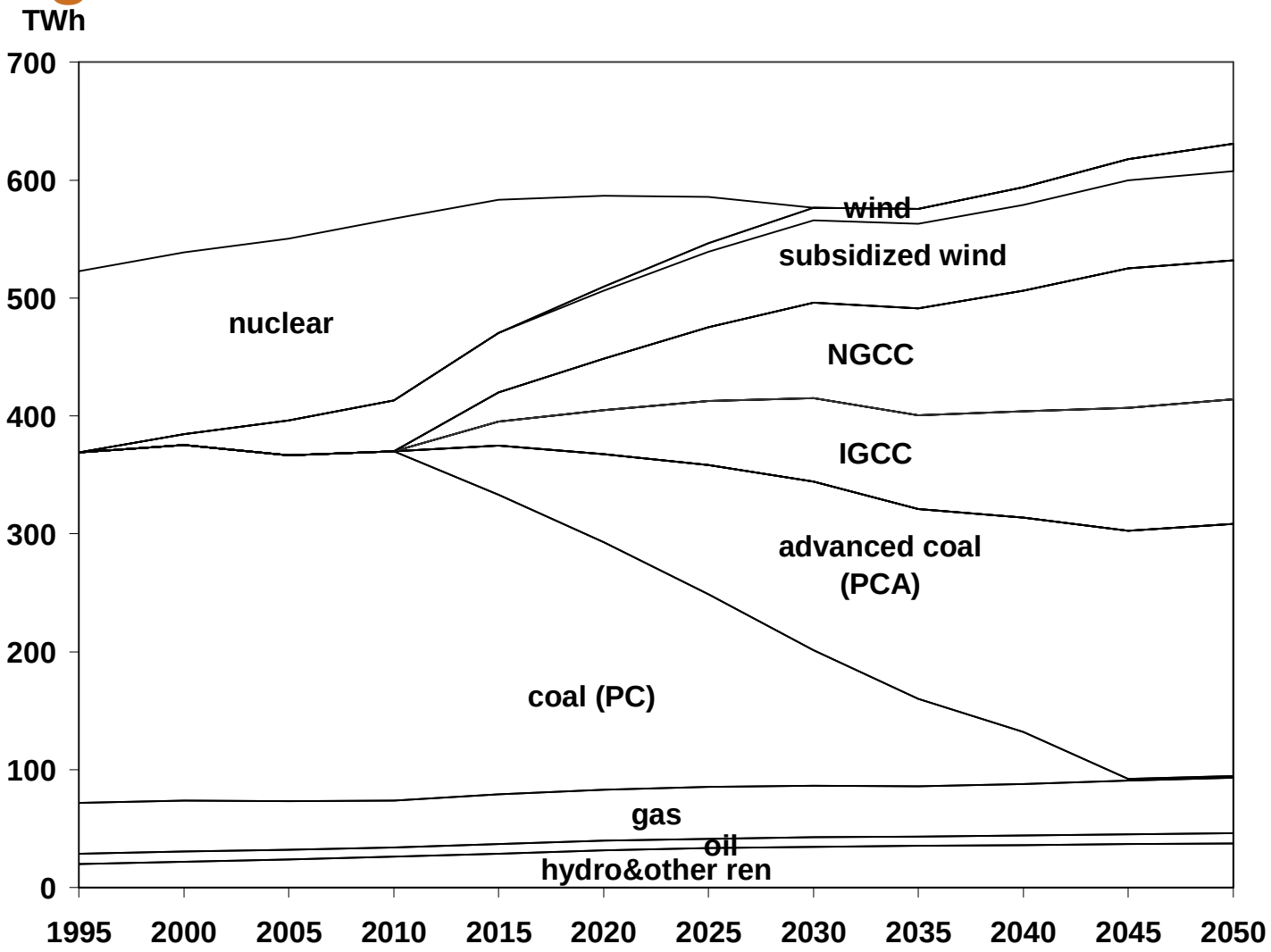
COE = capital cost + labor cost + fuel cost
+ (capture + transport/storage cost)

Electricity sector in SGM Germany

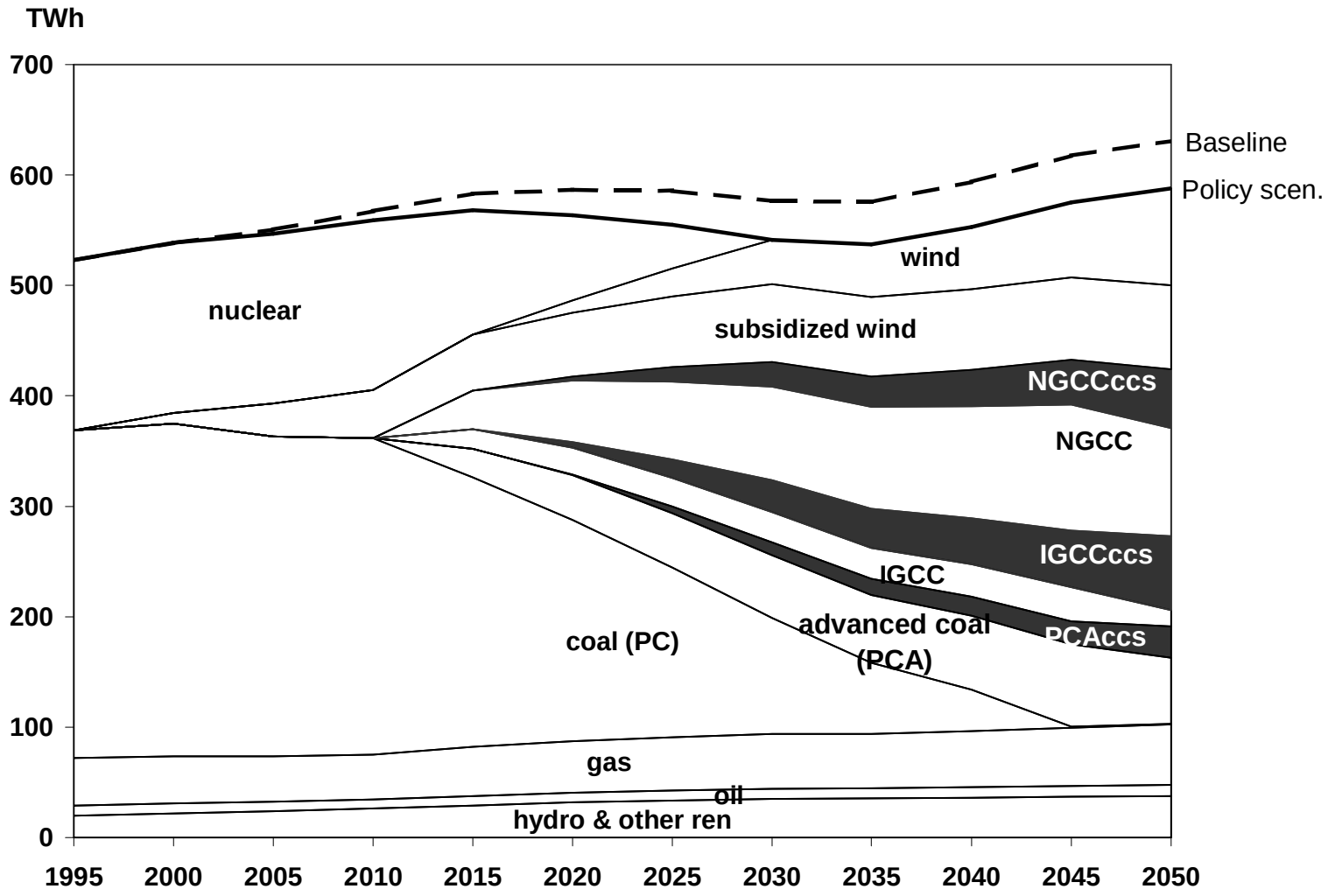
- All production sectors other than electricity represented by single CES production function
- Each electric generating technology represented by fixed-coefficient production function
- Electricity sector uses a nested logit structure to allocate new investment to generating technologies



SGM Results: baseline electricity generation



Electricity sector results – stepwise policy case



Log-Mean Divisia (LMDI) Decomposition

$$C = \sum_i \sum_j C_{ij} = Q \sum_i \frac{Q_i}{Q} \frac{E_i}{Q_i} \sum_j \frac{E_{ij}}{E_i} \frac{C_{ij}}{E_{ij}}$$

C = total industrial CO_2 emissions

C_{ij} = emissions from fuel j in industry i

Q = gross output across industrial sectors

E_i = total energy consumed in industry i

E_{ij} = energy consumed from fuel j in industry i

Source: Ang, B.W. (2005). “The LMDI approach to decomposition analysis: a practical guide.” *Energy Policy* **33**: 867-871.

Variation of LMDI for Electricity

$$C_{elec} = \sum_k C_{elec,k} = Q \frac{Q_{elec}}{Q} \sum_k \frac{Q_{elec,k}}{Q_{elec}} \frac{E_{elec,k}}{Q_{elec,k}} \frac{C_{elec,k}}{E_{elec,k}}$$

C_{elec} = CO_2 emissions from electricity generation

$C_{elec,k}$ = emissions from electricity technology k

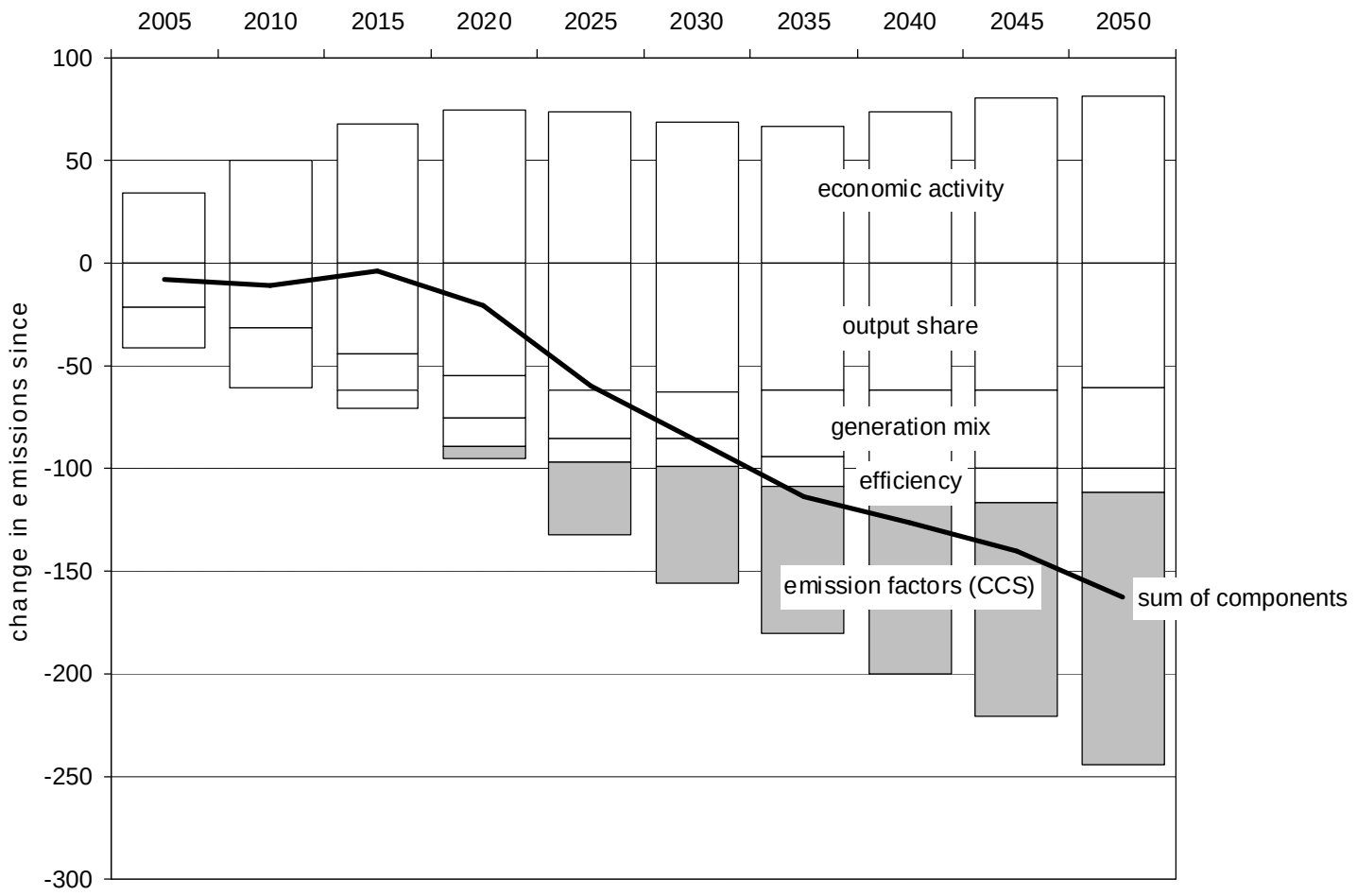
Q = gross output across industrial sectors

Q_{elec} = gross output for electricity (GWh)

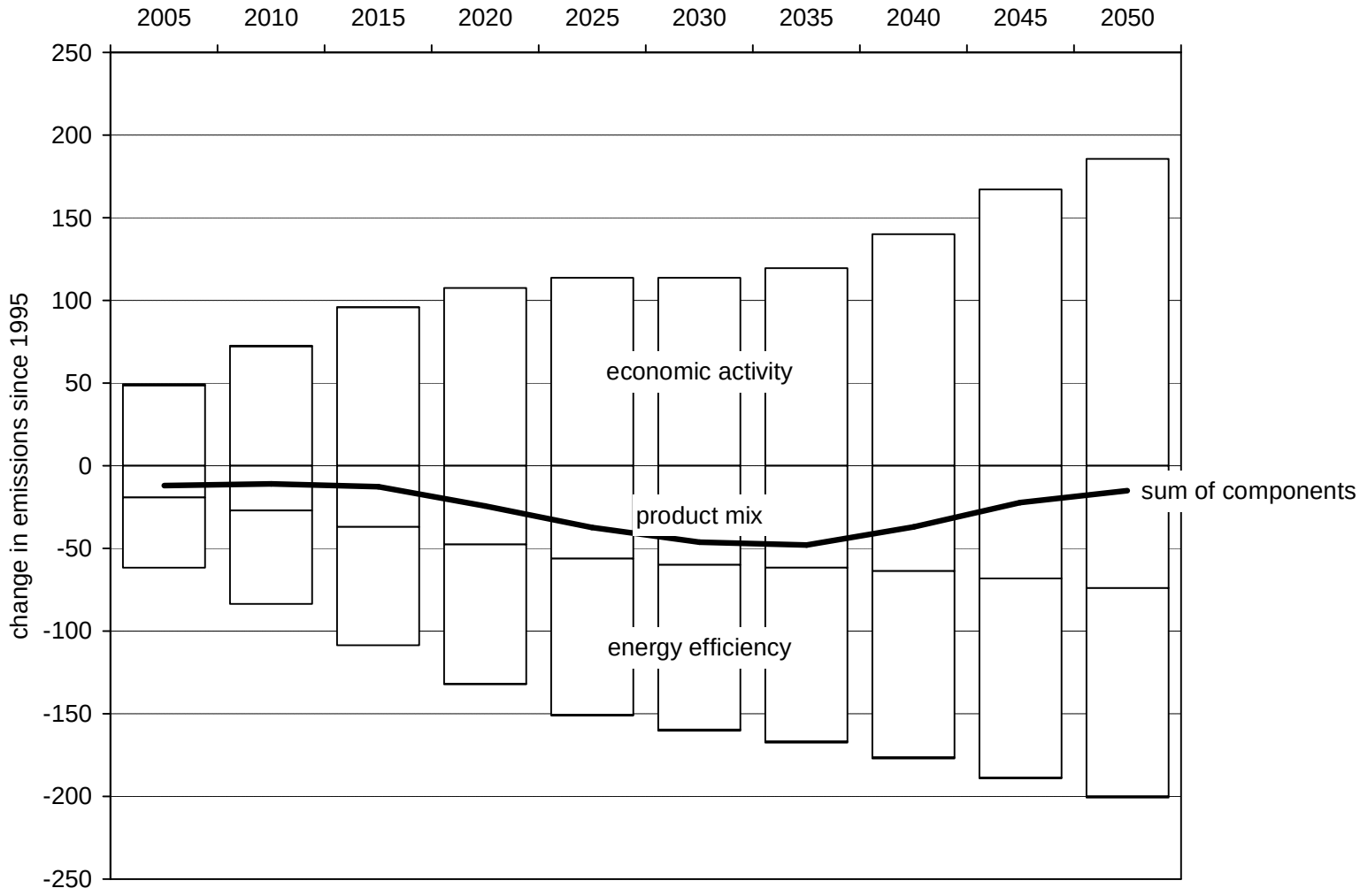
$Q_{elec,k}$ = output for electricity technology k (GWh)

$E_{elec,k}$ = energy consumption by electricity technology k

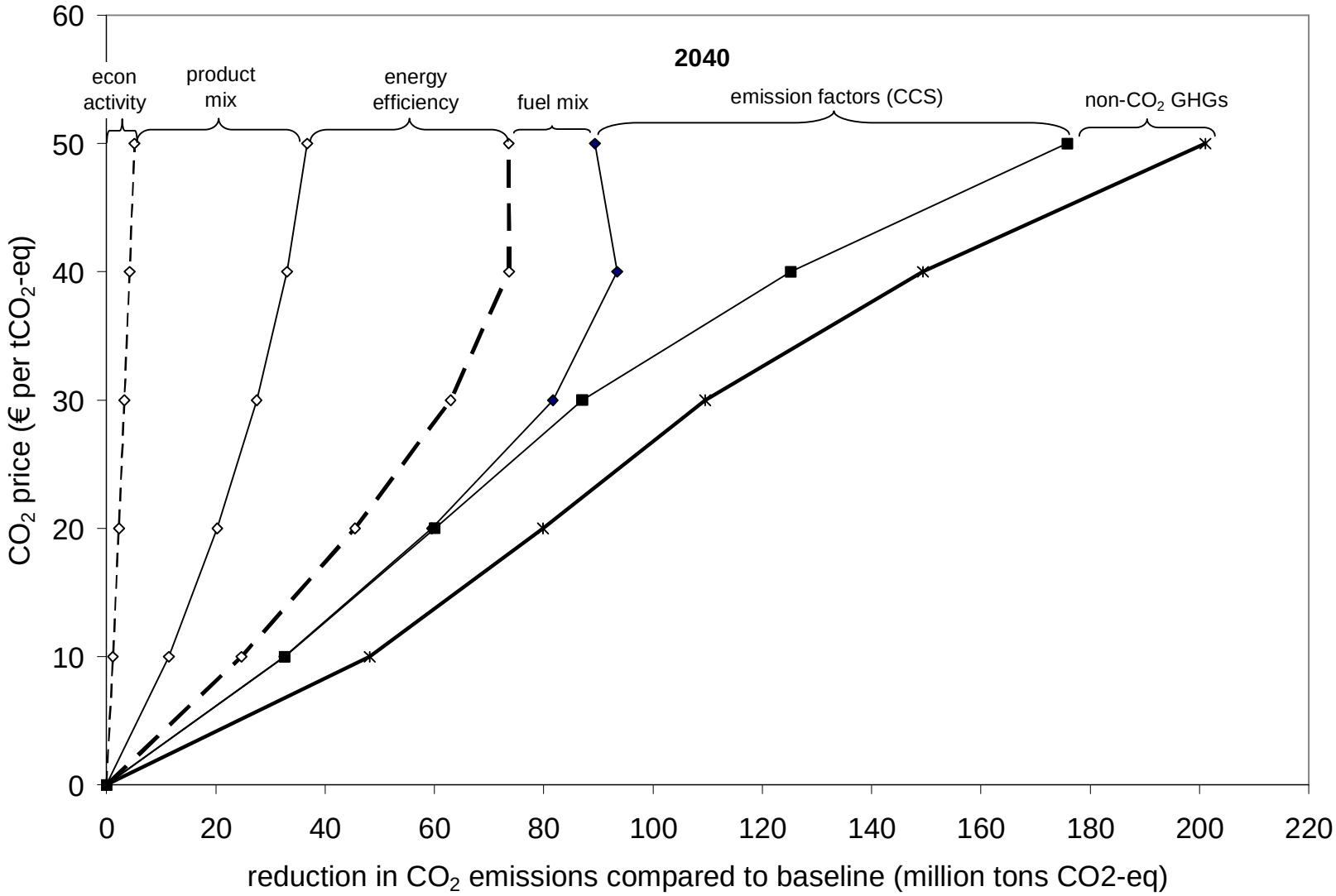
Decomposition of electricity sector CO_2 emissions over time, relative to model base year (1995), for the stepwise policy scenario



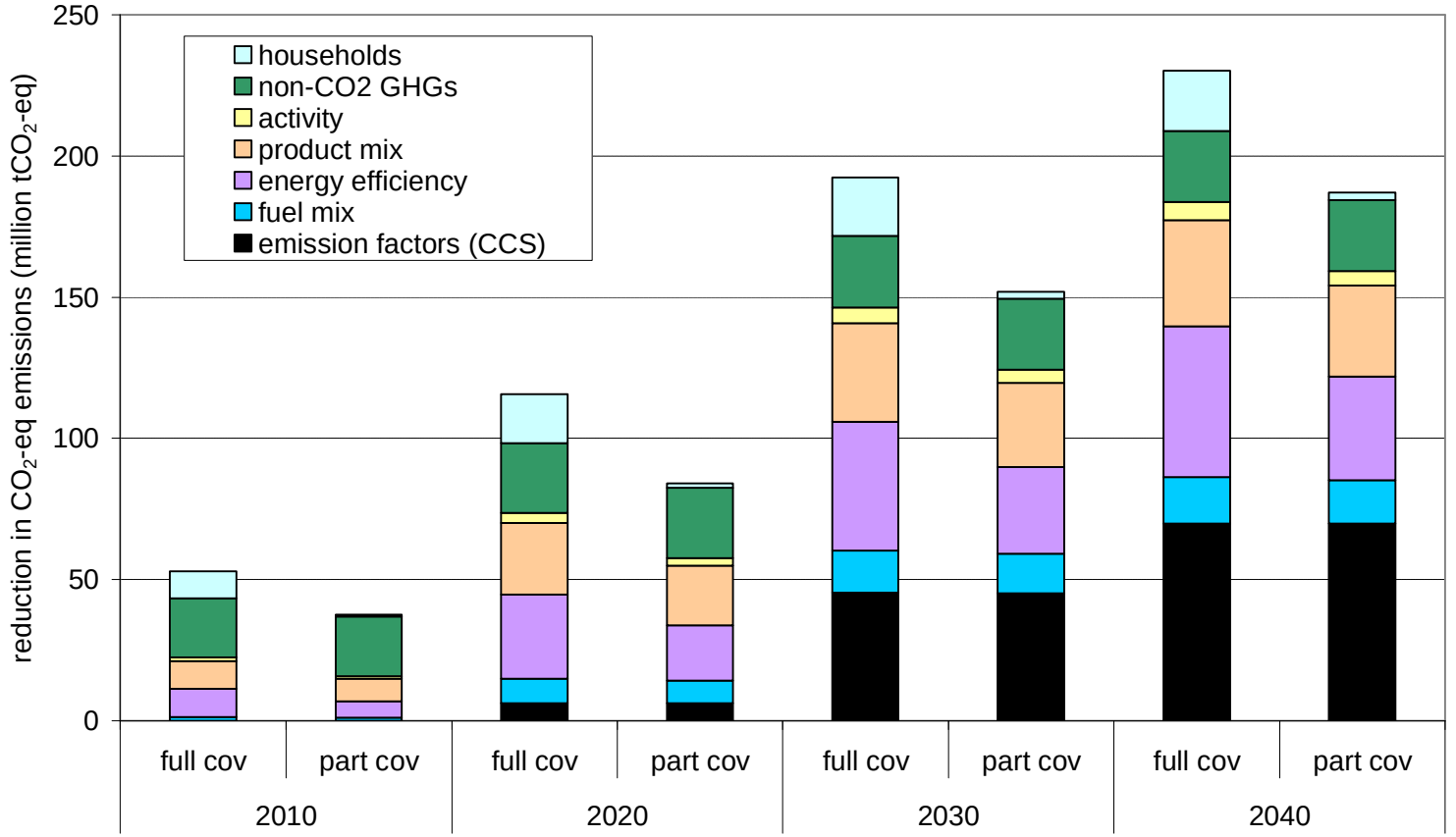
Decomposition of industrial CO_2 emissions (excluding electricity) over time, relative to model base year (1995), for the stepwise policy scenario



Simulated emissions reductions over a range of CO_2 prices, Germany 2040



Decomposition of emissions reduction with a stepwise increasing CO_2 price fully and partially covering the economy



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
- Primary contribution: Formal decomposition of the energy efficiency component into production (energy) efficiency and output shift components