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Future role of renewable energy in Germany against the background of climate change mitigation and liberalisation

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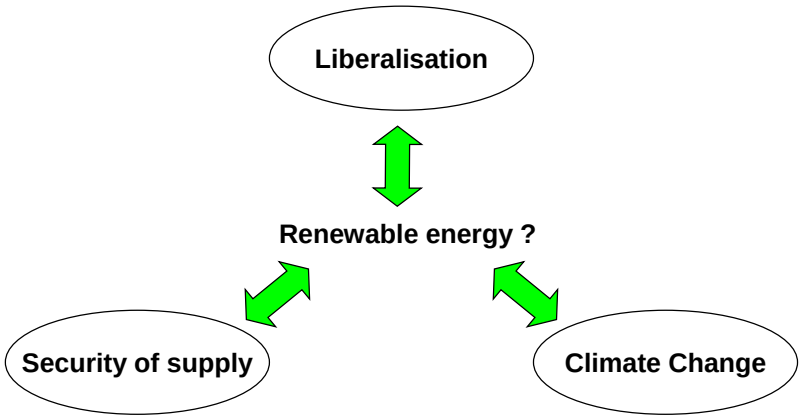
Overview

- **Renewables in Germany**
- **Methodology**
- **Scenario analysis and variations focussing on the electricity sector**
- **Conclusions**

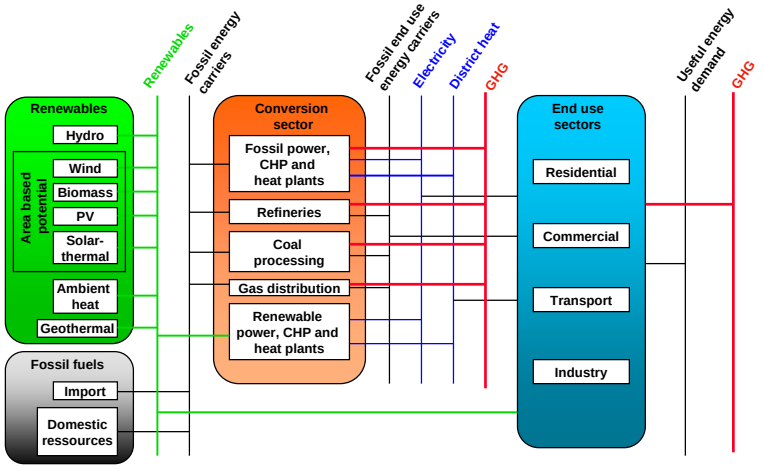
Conditions and challenges in the energy sector



Renewables in Germany: Potential and Usage

	Technical Potential						Usage in 2002	
	Fuel	Area	Supply		Demand		Electricity [TWh]	Heat [PJ]
Renewable energy carrier	[PJ]	[Mio. ha]	Electricity [TWh]	Heat [PJ]	Electricity [TWh]	Heat [PJ]		
Hydro Power (without pump storage)			24.7		23.7		19.9	
Wind								
Onshore		2.61	247.3		35-199		16.5	
Offshore		0.285	129				0	
Solarthermal								
Roof		0.08		864				6
Free areas		0.4		4 340				
Photovoltaics								
Roofs, Facade		0.1	131		35-218		0.21	
Free areas		0.4	543					
Heat pumps								
Ground				1 880		3 052		15-17
Ambient Air				unlimited		1 800		
Geothermal								
Hydrothermal				5 140		1 175		0.6
Deep sonde				3 010		2 061		
Power plants			321		8.7-321			
Biomasse								
solid	837-956	2	70-80	419-478	67-76	398-454	1.3	168-182
liquid	34		4	16	3	15	0.04	0.06
gaseous	342-402		29-34	188-221	27-32	179-210	1	3
							39.0	193-207

System analysis viewpoint



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Methodology

Optimising energy system model MARKAL/TIMES

- Bottom-up model, partial-equilibrium
- Perfect competition, perfect foresight
- Minimise total system cost subject to technical and energy political constraints
- Results: energy flows, investments, emission flows, costs, prices

Analysis tools/steps:

- Balance model based on optimisation results:
  - To calculate average emissions and costs related to an energy flow or the overall generation of an energy carrier
- Price-formation equations (dual problem, representation by digraphs):
  - To evaluate the competitiveness of a technology taking into account GHG constraints, renewable quotas, etc.
- Sensitivity analysis (determination of stability intervals based on optimal matrix partition):
  - To analyse the effect of marginal changes in input parameter on the solution and also identify the price-setting activities
- Parametric programming:
  - To vary input data on a larger parameter interval

MARKAL/TIMES energy system model for Germany

- Time horizon 1995-2050
- Ca. 120 conversion and 380 end-use technologies
- End use sectors:
  - Domestic
  - Industry
  - Commercial
  - Transport
- Conversion sector:
  - Electricity and district heat generation
  - Petroleum sector
  - Coal sector
  - Gas sector
  - Non-energetic use
  - Renewable energy sources
  - Hydrogen sector

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Scenario characterisation

- **Reference scenario (REF):**
  - Phase-out of nuclear energy
  - No green electricity quota and no GHG mitigation policy
  - Net import of conventional electricity zero after 2005
  - Option to import green electricity (up to 20% of net electricity consumption in 2050)
  - EU directive on the promotion of biofuels in the transport sector (2% of fuel consumption in 2010, 5.75% in 2010)
- **Green electricity scenario (GE):**
  - Quota for the production of electricity by renewables

	2010	2020	2030	2040	2050
Green electricity quota	12.5%	20%	30%	40%	50%

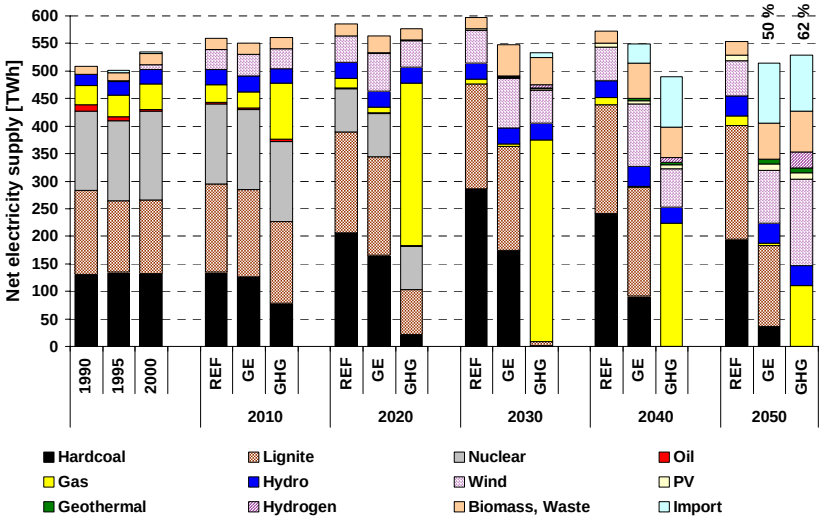
- **GHG mitigation scenario (GHG)**
  - GHG reduction target

	2010	2020	2030	2040	2050
GHG reduction relative to 1990	21%	35%	50%	65%	80%

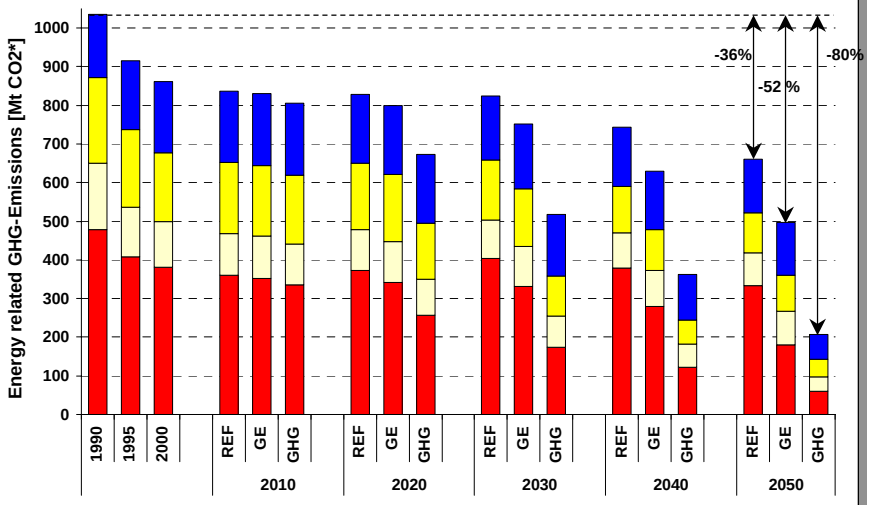
Socio-economic assumptions

	Unit	2000	2010	2020	2030	2050
Population	Mio.	82.2	82.1	80.8	77.9	67.8
GDP						
Absolute	Billion €	2023	2438	2882	3286	3989
		-	2000-2010	2010-2020	2020-2030	2030-2050
Growth rate	%	-	1.9%	1.7%	1.3%	1.0%
Residential sector						
Single family houses	Mio. m^2	1880	2155	2425	2493	2356
Multi family houses	Mio. m^2	1428	1578	1717	1738	1616
Residential area per capita	m^2	40.2	45.5	51.3	54.3	58.6
Transport sector						
Passenger	Billion Pkm	968.1	1090.7	1138.2	1139.1	1026.9
Goods	Billion Tkm	483.1	607.4	732.4	839.2	964.4
Energy prices (Import)						
Crude oil	€/GJ	2.81	3.56	4.31	5.06	6.57
Natural gas	€/GJ	2.15	2.84	3.52	4.2	5.57
Hard coal	€/GJ	1.36	1.43	1.59	1.76	2.09

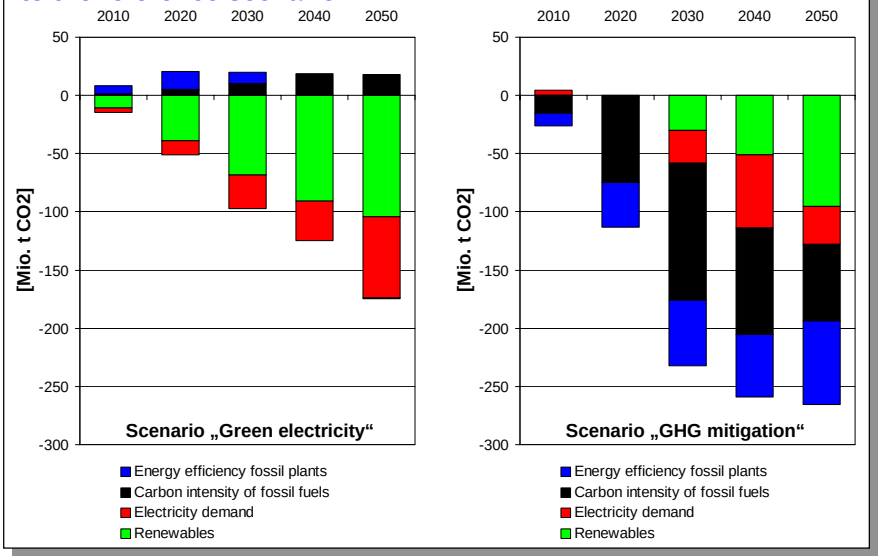
Net electricity supply



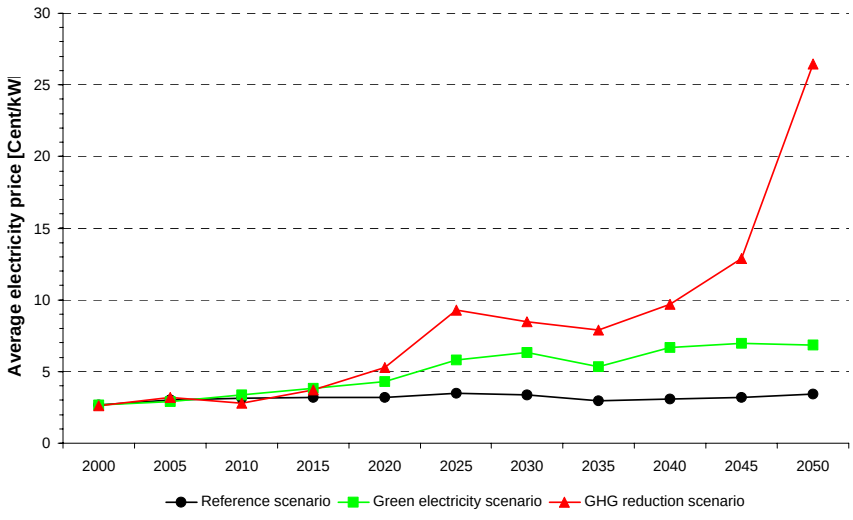
GHG Emissions



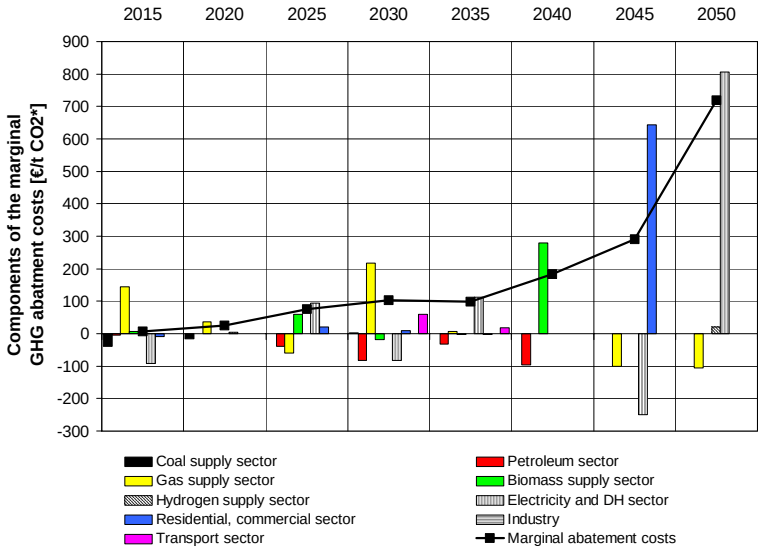
Decomposition of change in CO_2 emissions from electricity relative to the reference scenario



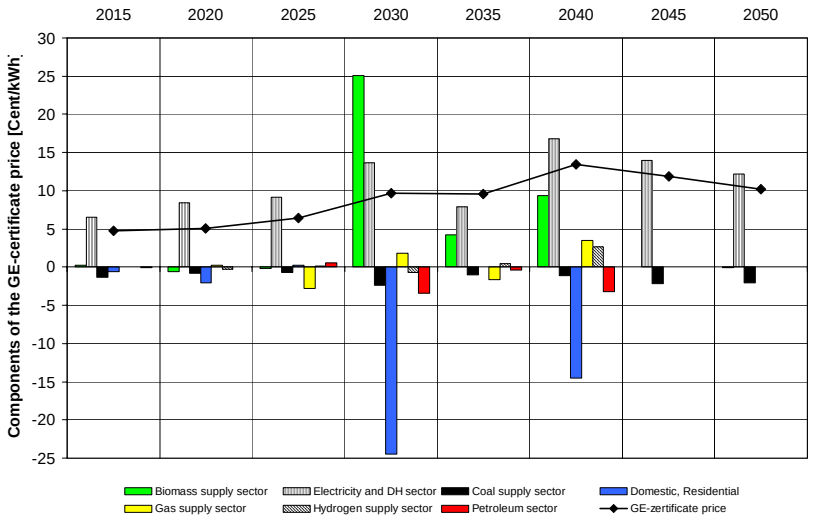
Electricity price



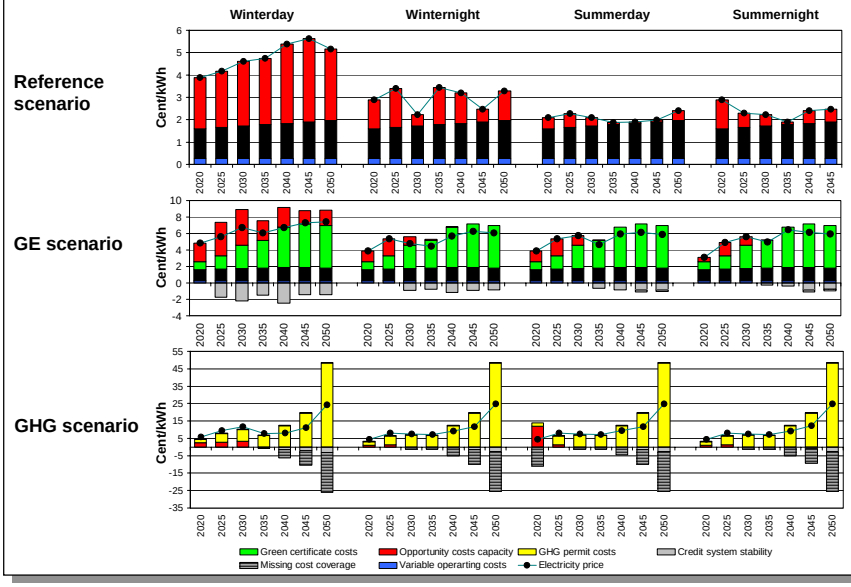
Emission permit price decomposition



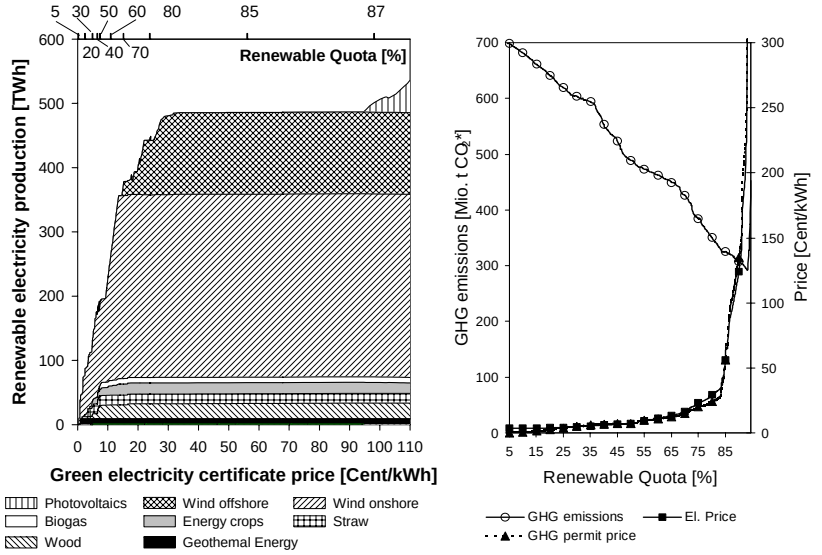
Decomposition of green electricity certificate price



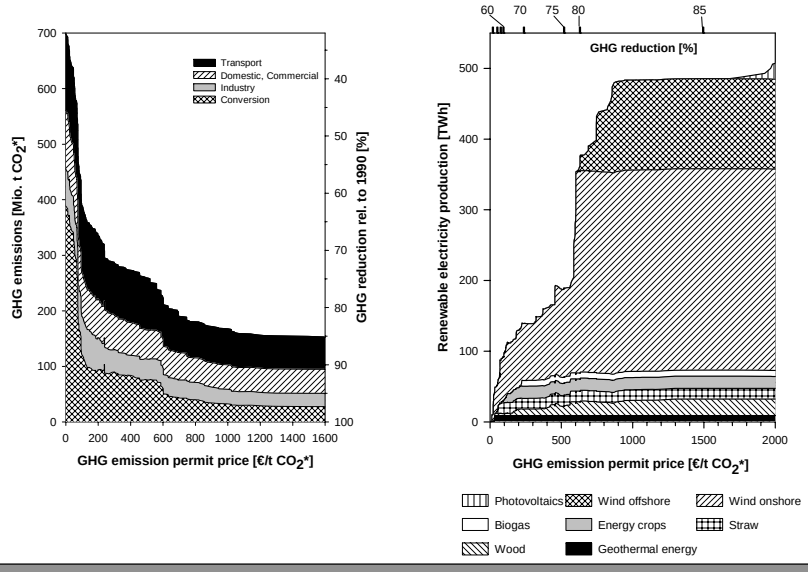
Decomposition of electricity price for a coal power plant



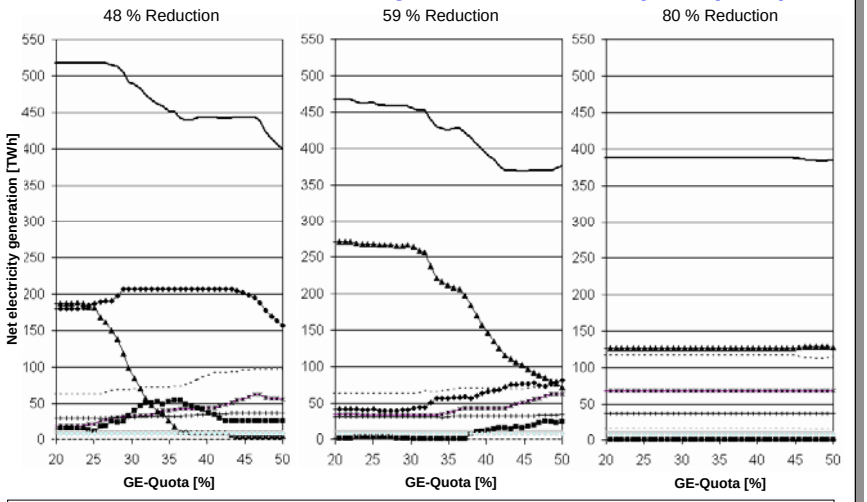
Supply curve for green electricity in 2050



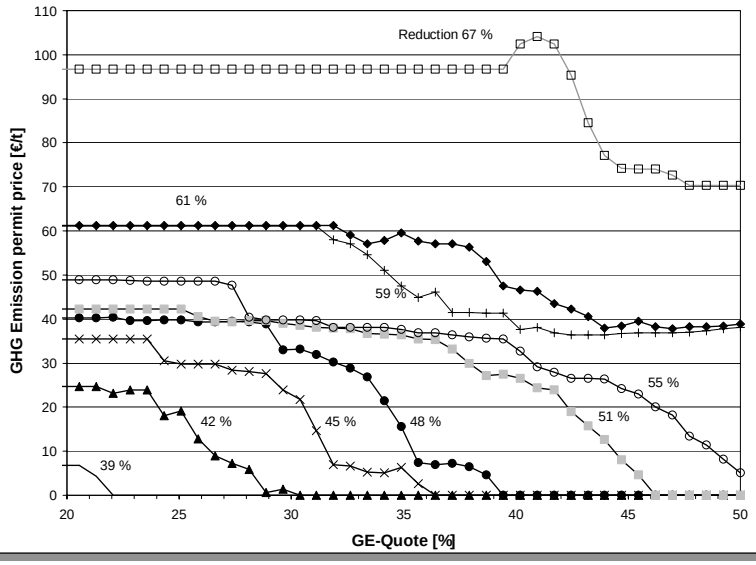
Renewable electricity vs. emission permit price in 2050



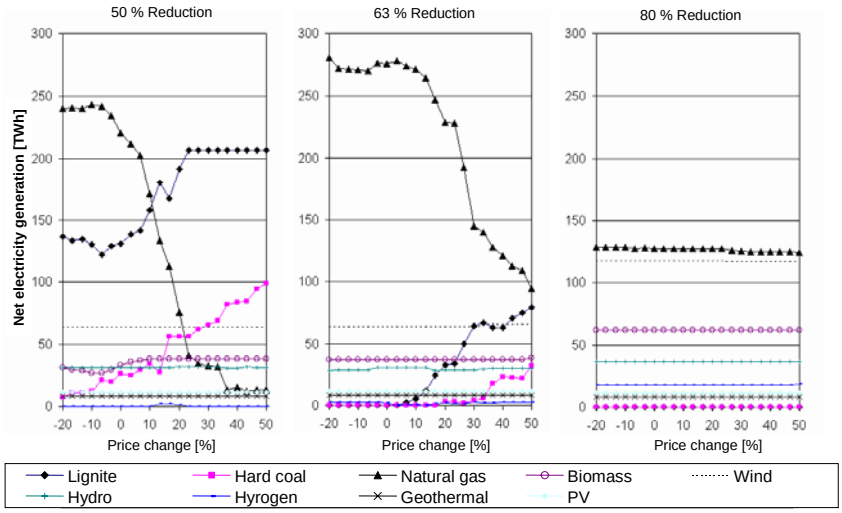
Variation of GHG reduction target and renewable quota (2050)



Variation of GHG reduction target and renewable quota (2050)

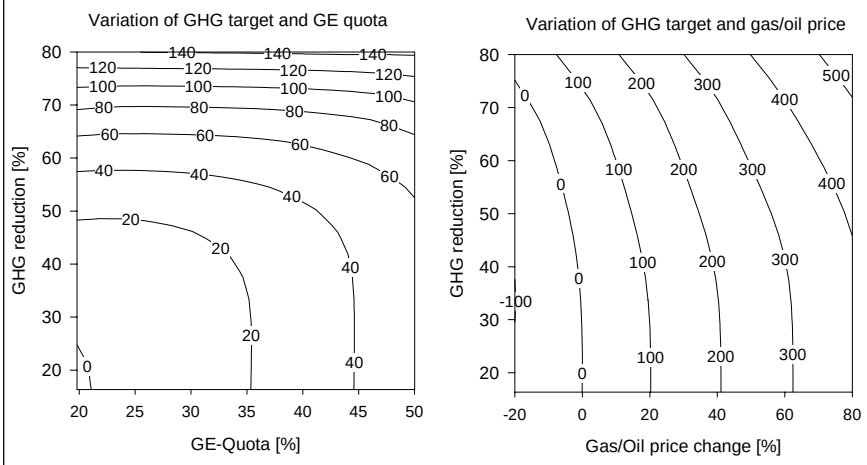


Variation of gas/oil price and renewable quota (2050)



Discounted system costs in the variations

[Billion €$_{00}$ discounted to 1998]



Conclusions

- Without policy instruments (i.e. subsidies) or without a climate change abatement policy an increase in renewable electricity generation is not competitive under current framework conditions
- Climate change abatement policy:
  - Up to a reduction target of 50 % gas becomes the major fuel
  - Hydro, geothermal energy, biomass and wind are cost-effective mitigation options (among others) when the reduction target becomes higher than ca. 50 %
  - Critical issue: assumption on conventional electricity net import of zero
- Green electricity quota:
  - Renewable electricity generation displaces mainly fossil generation by gas and hard coal
  - Part of the GHG reduction is due to electricity saving measures in the end-use sectors because of the higher electricity prices
- Variation of GHG target, green electricity quota and gas price:
  - The green electricity quota reduces the GHG permit price at the cost of the electricity consumers
  - For high reduction targets renewable electricity generation is independent from a quota
  - Increase in gas price does not favour renewable electricity generation but hard coal and lignite with a compensation for the increased emissions in other sectors

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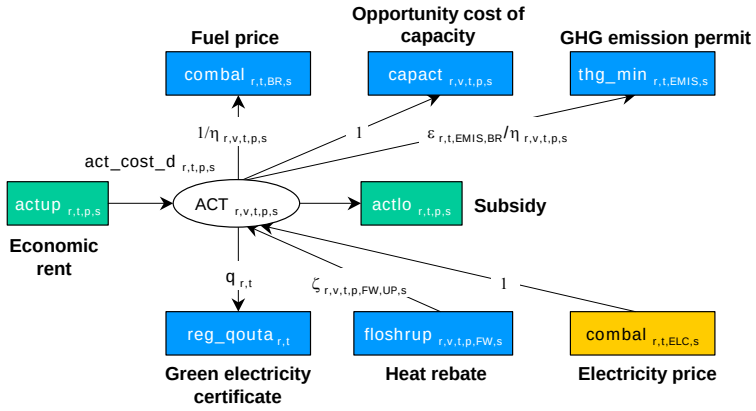
Supplementary slides

Renewables in Germany: Policy measures

- Direct instruments:
  - Renewable energy sources act (fixed feed-in tariff)
  - Market incentive programme to benefit renewable energies(grants/loans for bioenergy, solar PV, solar thermal, geothermal energy)
  - KfW CO_2 building remediation programme (loans for solar panels, heat pumps,)
  - KfW CO_2 reduction programme (loans for solar thermal panels)
  - Home ownership subsidy (grants for solar thermal panels)
  - Combined heat and power law (part of biomass not covered by renewable energy sources act)
  - ERP environmental and energy saving programme (low-interest loans for renewable energy projects for private companies)
  - EU directive on biofuels (binding targets for the share of biofuels in the transport sector)
  - EU directive on the promotion of electricity produced from renewable energy sources (indicative target for Germany 12.5 % in 2010)
- Indirectly affected by:
  - Eco-tax reform (fossil fuel taxes to reduce social insurance costs)
  - Energy saving ordinance (low-energy standard for new houses, requirement to replace inefficient furnaces, exception for renewables)

Price formation equations

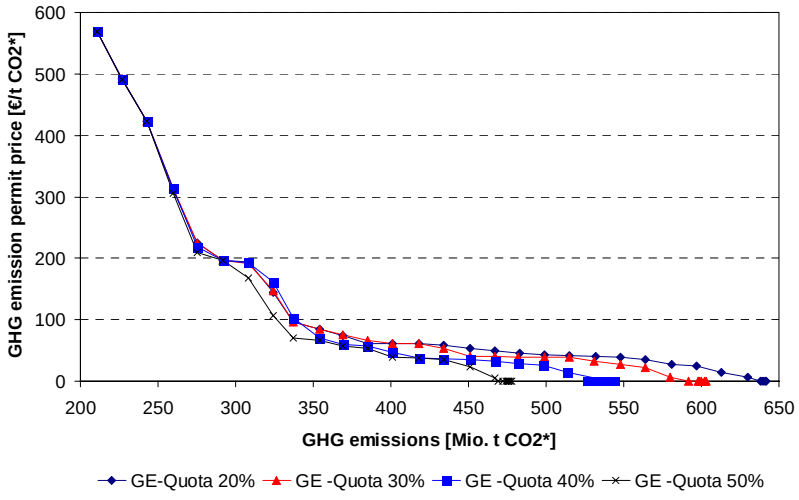


$$ACT_{r,v,t,p,s}:$$

$$act\_cost\_d_{r,t,p,s} + \frac{1}{\eta_{r,t,p,s}} \cdot combal_{r,t,BR,s} + capact_{r,v,t,p,s} + \frac{\varepsilon_{r,t,p,EMIS,BR}}{\eta_{r,t,p}} \cdot thg\_min_{r,t,EMIS,s} +$$

$$q_{r,t} \cdot reg\_quota_{r,t} - \zeta_{r,v,t,p,FW,UP,s} \cdot floshrup_{r,v,t,p,FW,s} + actlo_{r,t,p,s} - actup_{r,t,p,s} \geq combal_{r,t,ELC,s}$$

GHG abatement cost curve in 2050



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Technical and economic characterisation of renewable electricity technologies

	Unit	Wind onshore		Wind offshore	
Year		2010	2050	2010	2050
Capacity	MW	1.5	2.5	2	5
Investment costs	€/kW	1155	950	1640-1960	1370-1500
Fixed operating and maintenance costs	% Inv./a	7.3	7.3	9.5	9.5
Full load hours	h	1250-3000	1300-3200	3592-3781	3592-3781

	Unit	PV		Geothermal (HDR, ORC)	
Year		2010	2050	2010	2050
Capacity	MW	0.5	0.5	100	50
Investment costs	€/kW	5130	2360	4300	3400
Fixed operating and maintenance costs	% Inv./a	1	1	4.5	4
Full load hours	h	1000	1000	6500	7000

Technical and economic characterisation of renewable electricity technologies

	Unit	Wood		
Plant type		Backpressure CHP	Internal combustion	Combinded Cycle
Capacity	MW_{el}	10	5	15
Efficiency electricity	%	30	40	50
Efficiency heat	%	55	48	42
Overall efficiency (incl. gasification)	%	85	62	78
Investment costs	€/kW	2600	2080	2500
Fixed operating and maintenance costs	% Inv./a	4.1	7.5	7.5
Additional maintenance costs	€/kWh_{el}	-	0.02	-

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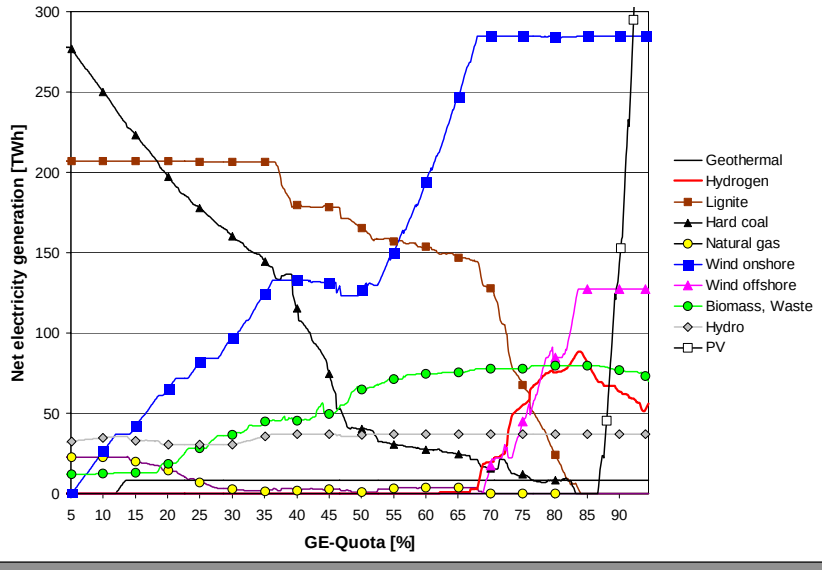
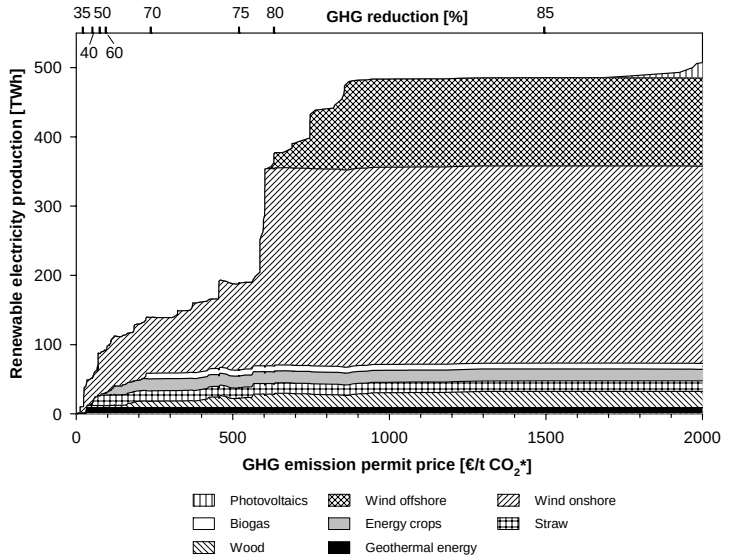
Net electricity generation in 2050



Renewable electricity vs. emission permit price in 2050



Supply curve for green electricity in 2050