Internalisation of external cost in the power generation sector:

Analysis with Global Multi-regional MARKAL Model

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Structure of the presentation

- Scope of the study and modelling framework
- Basic assumptions and scenarios
- Definition of external cost
- Results
  - Structural changes
  - Environmental impacts
  - Cost impacts
- Conclusions

Scope of analysis

Estimate the economic, environmental and structural impacts of a full internalisation of external costs in the electricity generation, assuming that the additional charges will reflect the environmental and health damages from local pollution, climate change and other burdens.

Modelling framework

Global Multi-regional MARKAL Model (GMM):

- Five world regions: North America, OECD, Eastern Europe and Former Soviet Union, Asia, Latin America with Africa and Middle East
- Endogenous technological learning (‚Learning-by-doing‘)
- Learning spill-over across regions
- Global trade of energy/environmental commodities (fuels, emissions permits, green electricity)
- Partial equilibrium (MARKAL-ED)

Scenarios

Three main scenarios are analysed with endogenous technological learning (ETL):

BNNL – **B**usiness-As-Usual, **N**o local, **N**o global externalities, with ET**L**

BXLL – **B**AU, E**x**ternal costs from **L**ocal pollutants, with ET**L**

BXGL – **B**AU, E**x**ternal costs incl. Local pollutants and **G**lobal warming impacts, with ET**L**

Basic definitions / assumptions

Region	Population density	Sulphur content in the coal [%]	Starting year of external charges
NAME	Medium	1	2010
OOECD	High	1	2010
REEU	Medium	1	2010
ASIA	High	1	2010
LAFM	Medium	1	2010

- External costs are charged to every unit of electricity produced from each power plant
- External costs are applied in all world regions from the same time period
- External costs are adjusted to the efficiency of each technology

Basic definitions / assumptions (cont.)

The GMM model has different options to react to the extra charges on the power generation:

- to pay (or not) a tax on production from a technology
- to install (or not) a system with DeNOx, DeSOx, or C-capturing
- to reduce the energy/electricity demand
- to apply fuel switching and technological change

External cost

Impacts from following burdens are considered beside the air emissions:

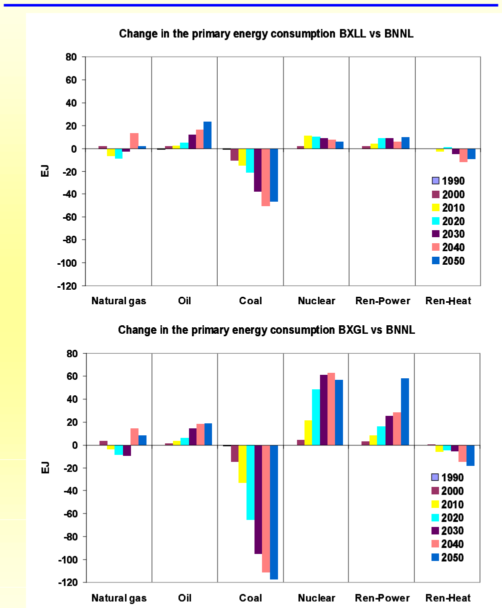
- Solid wastes
- Liquid wastes
- Risk of accidents
- Occupational exposure to hazardous substances
- Noise
- Others (e.g. exposure to electro-magnetic fields, emissions of heat)

Technology	External costs (¢EUR95 / kWh)	
	excl CO2	*incl CO2*
Fossil based power plants		
Coal conventional electric	5.7 - 11.7	7.5 - 13.6
Coal conventional electric with DeSulf/DeNOx	0.7- 1.0	2.5 - 3.0
Coal conv. with DeSulf/DeNOx and CO2 scrubber	0.9 - 1.3	1.3 - 1.9
Coal advanced electric	0.8 - 1.2	2.1 - 2.8
Coal advanced electric with CO2 scrubber	0.9 - 1.5	1.2 - 1.9
Coal IGCC (CHP)	0.6 - 0.9	2.4 - 3.0
Coal IGCC (CHP) with CO2 scrubber	0.8 - 1.0	1.1 - 1.4
Gas combined cycle	0.3 - 1.2	0.9 - 1.9
Gas combined cycle with CO2 scrubber	0.3 - 1.4	0.4 - 1.6
Gas turbine	1.3 - 1.8	2.3 - 2.9
Gas steam conventional	2.0 - 3.2	3.0 - 4.2
Cogenaration gas turbine	1.4 - 1.9	2.4 - 3.0
Gas fuel cell	0.3	0.9
Hydrogen fuel cell (CHP) in industry	0.3	0.9
Hydrogen fuel cell (CHP) in res&com.	0.3	0.9
Oil electric	1.4 - 2.7	2.7 - 4.4
Nuclear and renewable power plants		
LWR Nuclear plant	0.5	0.52
LWR Advanced nuclear plant	0.5	0.52
Hydro-electric plant	0.1	0.1
Solar photovoltaics	0.1	0.3
Solar thermal electric	0.1	0.3
Wind turbine	0.1	0.1
Biomass power plant	0.3	0.45
Geothermal electric	0.15	0.45

Structural Impacts

Primary Energy

- Total global primary energy consumption remains unaffected if external cost included
- The decrease in coal consumption is compensated by rising demand in oil, natural gas, nuclear and renewable energy



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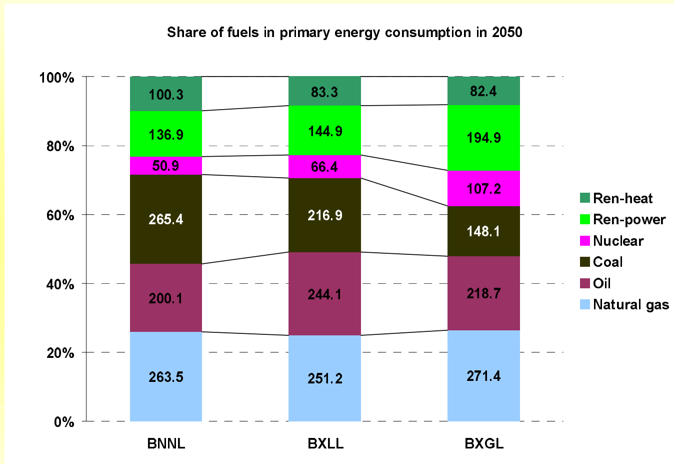
Global Primary Energy demand in 2050



- Primary energy: in BXLL and BXGL the consumption of oil, nuclear and renewables is increased, while the importance of coal is reduced

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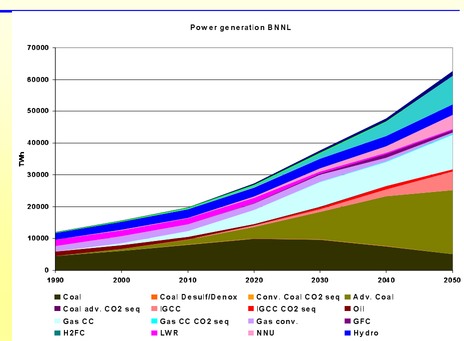
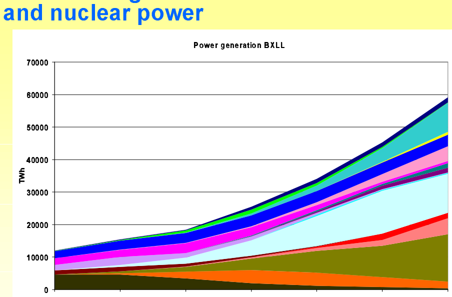
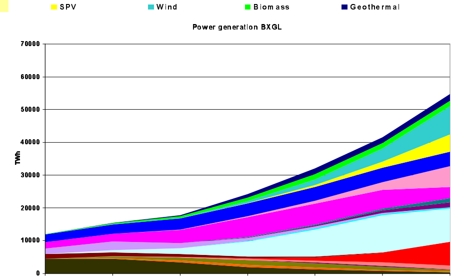
Electricity Generation

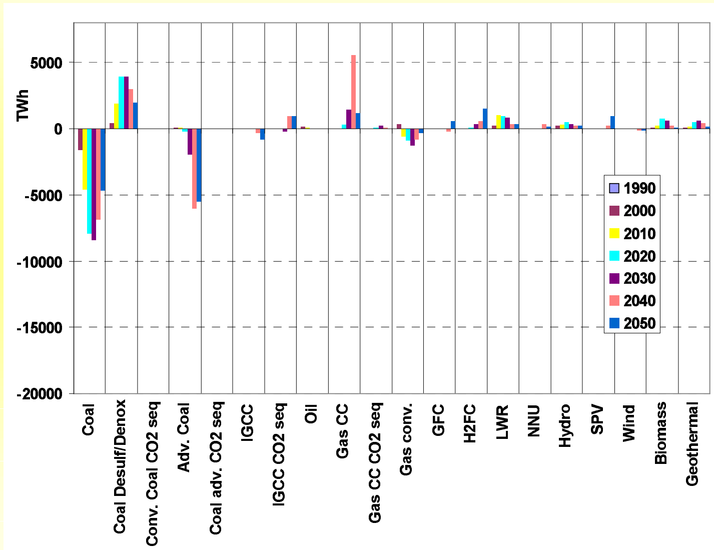
- Power generation in 2050 is decreased by 5.6% in BXLL and by 12.7% in BXGL, relative to the baseline.
- Changes in coal based generation: conventional coal eliminated, and replaced by ‚clean-coal' power plants (BXLL) and additionally, by C-sequestration technologies (BXGL)
- Increase in generation from renewables and nuclear power



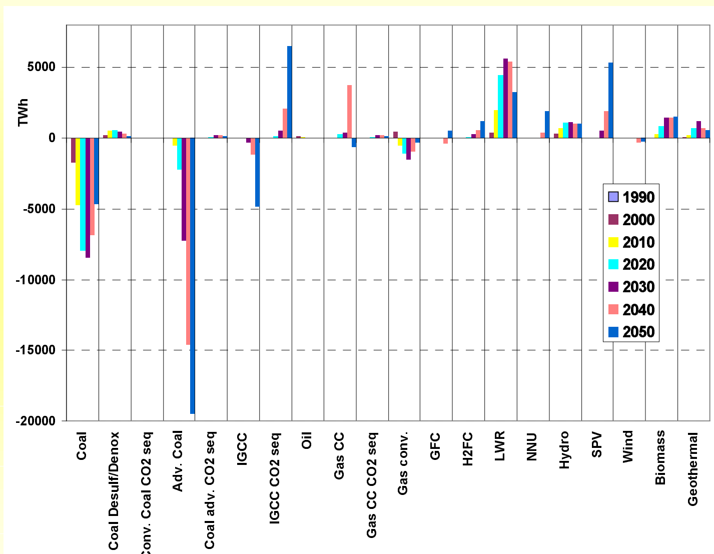




Change in the power production in BXLL over the baseline



Change in the power production in BXGL over the baseline



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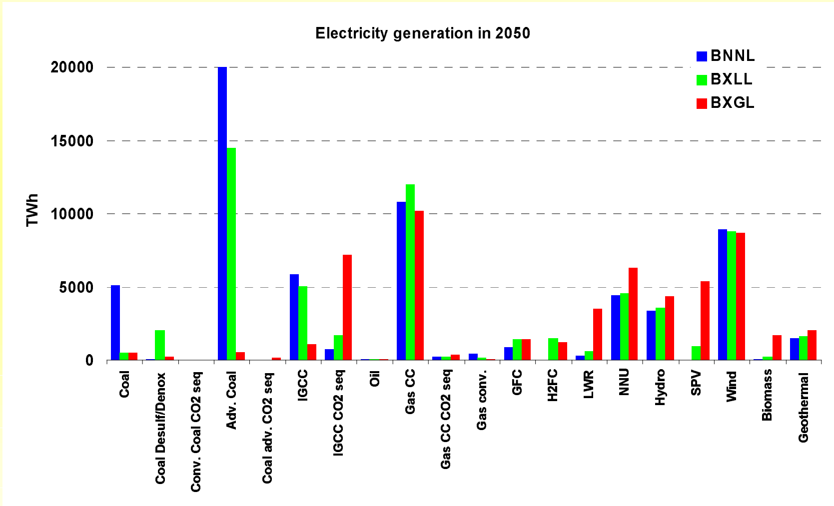
Electricity generation by technology in 2050



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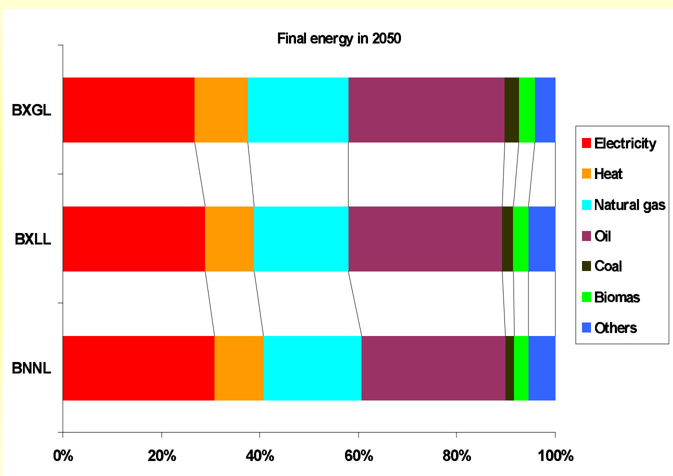
Global Final Energy demand in 2050



In both cases the final consumption of oil, natural gas, heat and biomass increases relative to the baseline, while demand for electricity is reduced (external costs are applied only to the power sector).

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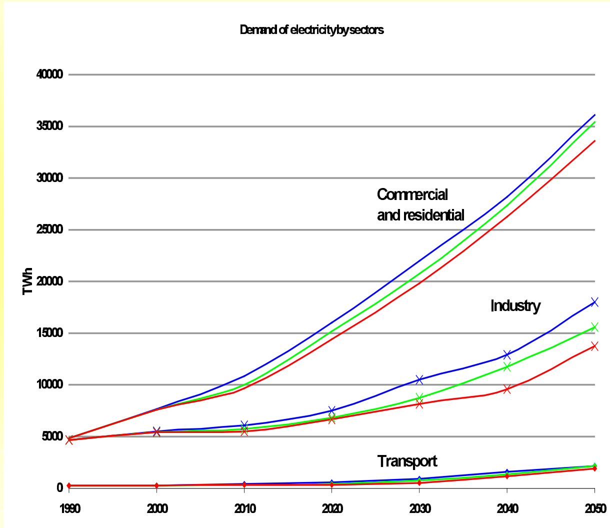
Development of electricity demand by sectors

- Demand for electricity is reduced in all sectors due to the increase in electricity price (partial equilibrium)
- The largest reduction is observed in the industrial sector (by 13.4% in BXLL and 23.6% in BXGL over the baseline) in 2050



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Environmental impacts

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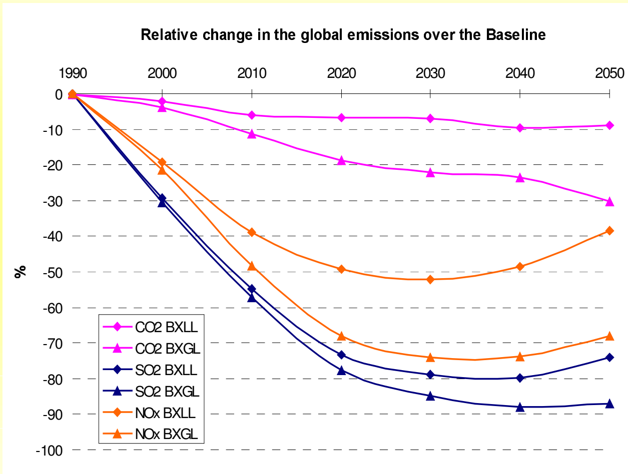
Global air emissions



- Significant emission-reducing effect in both externality scenarios

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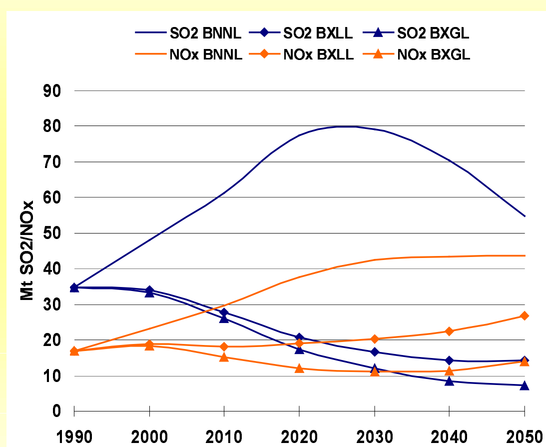
Global air emissions (cont.)

- SO2 emissions from the power production reduced by 73% in BXLL and 78% in BXGL cases by 2020
- NOx emissions are stabilised between 2020-2040, and slowly increase afterwards due to rising share of modern fossil technologies (i.e. advanced coal, NGCC)



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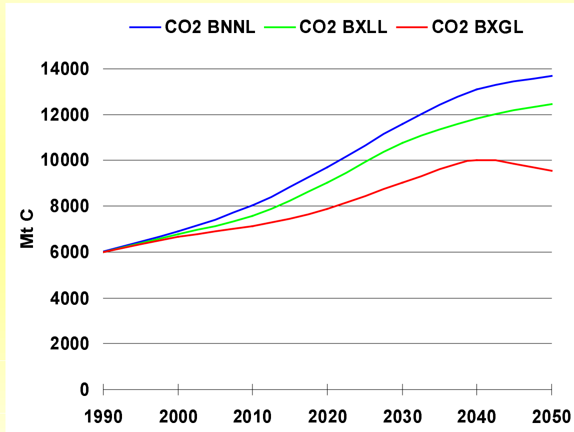
Global air emissions (cont.)

- In the BXGL case, CO2 emissions culminate around 2040 (i.e. at 10 Bt C) and then are reduced when carbon-sequestration becomes competitive



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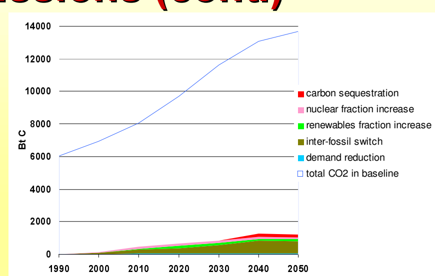
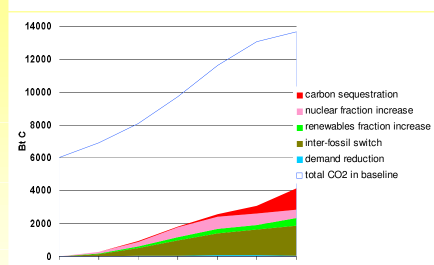
Global air emissions (cont.)

- Inter-fossil switching plays dominant role in carbon mitigation (63% of CO2 reduction in BXLL and 44% in BXGL case)
- Increase in nuclear energy fraction contributes with 30% to the total CO2 reduction in BXGL case in the time period 2010-2030
- Carbon-removal share in overall CO2 mitigation process in 2050 corresponds to 15% in BXLL case and 31.5% in BXGL case.





Economic impacts

Electricity generation cost analysis

Total electricity generation cost is calculated according this formula:

$$TGC = \frac{I * CRF}{Q} + \frac{FIXO\,\&\,M}{Q} + \frac{VARO\,\&\,M}{Q} + \frac{F}{Q} + \frac{E}{Q}$$

Where:

I	**= Capital investment cost**
CRF	**= Capital recovery factor**
Q	**= Annual plant output (kWhr)**
FIXO&M	**= Fixed O&M cost**
VARO&M	**= Variable O&M cost**
F	**= Fuel cost**
E	**= External cost**

$$CRF = df * \frac{(1+df)^n}{(1+df)^n - 1}$$

Where:

df	= discounting factor
n	= plant life time

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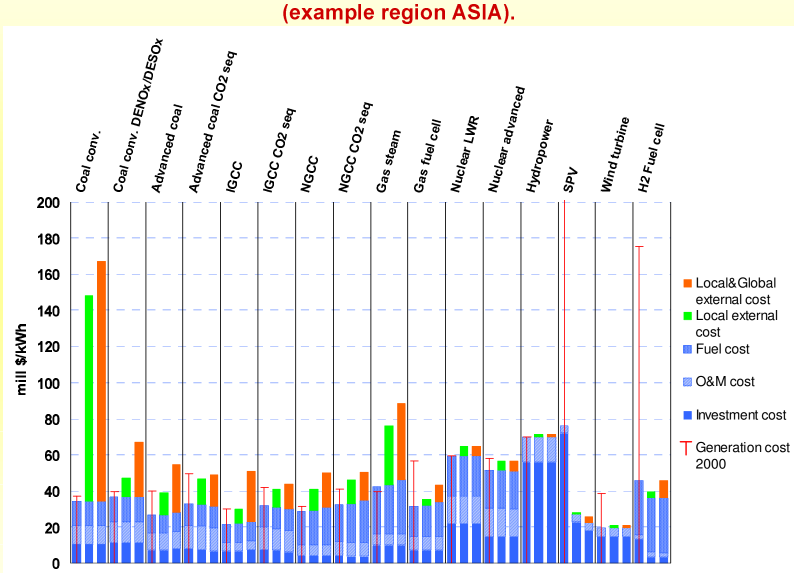
Break-down of the cost components for power generation by scenarios in 2050 (example region ASIA).



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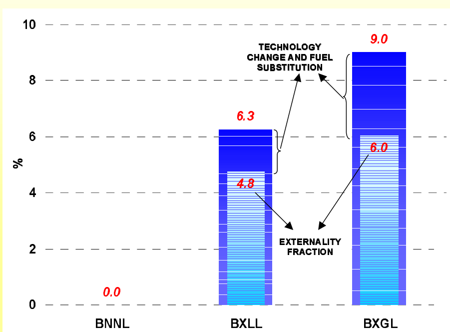
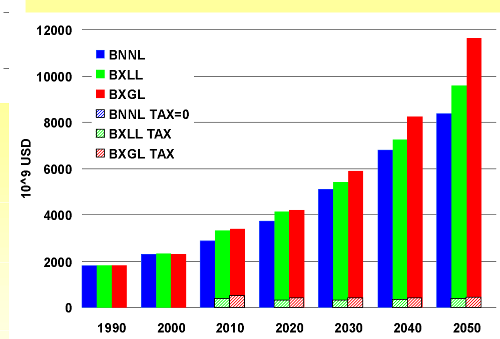
System Cost



High relative change in the objective function due to inclusion of the additional charges on the power generation

In the BXGL case, the total undiscounted system cost is much higher at the end of the time horizon, because of the stronger penetration of new and expensive technologies (C-sequestration)



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Conclusions

- Internalisation of externalities with and without climate change impacts fosters a fast introduction of emissions control systems and low-emitting power plants
- Both types of external costs have positive global and local environmental impacts due to significant emissions reduction
- Charging the „global“ externalities (BXGL case) leads to a strong decarbonisation effect, since the carbon sequestration technologies become competitive

Conclusions (cont.)

- The GMM model indicates substantial changes in the electricity production system (i.e., diffusion of new technologies and fuel switching), and some efficiency loss due to the use of scrubbers (DeNOx, DeSOx, and C-capturing)
- Externality charges on power generation reduce demand for electricity in industrial and res&comm sectors; electricity is substituted by natural gas and oil.
- Learning-by-doing is helping to moderate the level of external cost penalty