A Fundamental Analysis of Energy-Economy-Environment Interactions and Policy Options for Industrial Countries: The Case of Germany until 2030

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Abstract – In nearly all industrial countries there is a permanent discussion on energy policies to reduce GHG emissions without creating too severe increases in energy prices and losses in competitiveness and employment. Policies promoting energy efficiency, renewables, and CO2-pricing are often considered the instruments of choice. However, as climate policies are not yet fully globalized, the question remains: What mix and intensity of policy measures adequately balances the goals of environmental protection, competitiveness and energy security? Based on a novel methodological approach, this paper provides key findings of an extensive study on the effects of alternative energy policies. Three scenarios are quantified for Germany until 2030: The first extrapolates current policies, the second tries to balance the mentioned goals, the third focuses on environmental targets. The scenarios include alternative policies regarding i) post-Kyoto emission caps, ii) mechanisms of CO2-certificate allocation, iii) promotion of renewables, iv) cogeneration, and v) nuclear power. Results include investment dynamics in the power sector, generation by fuels, CO2-emissions, costs and prices of electricity. Emphasis is put on the demand side improving energy efficiency in households, transportation, and industries. Policy impacts on sectoral production and employment are highlighted. Sensitivity analyses are performed with respect to world energy prices.

This paper contains preliminary results of an ongoing research, financially supported by the German Association of the Electricity Industry (VDEW) and further partners. Final results will be available in spring 2007; the paper will be updated and completed then.

1. Background

The latest report of Nicholas Stern (2006) to the UK government on the economics of climate change as well as current activities of the EU Commission regarding a new European energy strategy are examples of a reinforced debate about energy policy on the national and international level. In nearly all industrial countries there is a permanent discussion on policies to reduce greenhouse gas (GHG) emissions and secure energy supply, while at the same time trying to avoid too severe increases in energy prices and losses in regional competitiveness.

The promotion of energy efficiency, low-emission or CO2-free technologies, and CO2-pricing are considered important elements of energy policy. The European Union has established an emission trading system, and promotes these elements via Green Papers and Directives. Their implementation, however, has to observe trade-offs between potential first-mover advantages of ambitious climate policies on the one hand, and the resulting costs and losses of regional competitiveness, growth, and employment on the other. Thus, as long as climate policies are not sufficiently globalized, policy-makers in industrial countries have to balance the goals of energy policy: environmental protection, energy security, and regional competitiveness.

The quantitative investigation of this crucial balance is the aim of the present paper: We explore what concrete mix and intensity of policy measures may balance the mentioned goals. To this end we develop various energy policy scenarios, as specified below.

2. Specification of policy scenarios

In order to analyse the effects of alternative energy policies on environmental protection, competitiveness, and energy security, we quantify alternative scenarios for the industrial country Germany – embedded in the European internal market – until 2030. Each scenario includes a mix of policy measures along the following dimensions:

- Post-Kyoto GHG Reduction Targets,
- Mechanisms for GHG-Certificate Allocation (NAP II extrapolation vs. Auctioning),
- Promotion of Renewables,
- Promotion of Cogeneration,
- Nuclear Power.

We specify three scenarios: The first extrapolates current policies, the second tries to balance the mentioned goals, the third focuses on environmental targets. Thus, the scenarios span a band-width of possible approaches to energy policy, reflecting the tension in the political discussion in the industrialized countries: Scenario I can be considered an ‘extreme’ scenario, in that the extrapolation of current trends is generally considered as not sustainable with respect to climate protection. Scenario III, on the other hand represents the extreme of putting priority to environmental targets, irrespective of the other policy goals. The middle scenario II tries to balance the goals of climate protection, competitiveness, and energy security. One further idea in specifying Scenario II is that governments concentrate on setting appropriate boundary conditions to the market, so as to support cost efficient achievement of policy goals with the help of market mechanisms. We characterize the three scenarios briefly (see Figure 1):

Scenario I: "Status-Quo Extrapolation"
This Scenario is characterized by a long-term stabilization of CO2-emissions on the level of the Kyoto-targets (-21% compared to 1990 for Germany, -8% for the EU), the prolongation of the current mechanisms of CO2-certificate allocation (especially the German NAP II based on costless allocation and technology-specific benchmarks after 2012), continued promotion of renewable energies and cogeneration, and a phase-out of nuclear power.

Scenario II: "Balancing Goals / Market Mechanisms"
This Scenario includes stronger efforts to reduce GHG emissions (-30% for Germany until 2030, -19% for the EU) and the allocation of CO2-certificates based on NAP II (based on costless allocation and technology-specific benchmarks after 2012). A market-based model to promote and integrate renewable energies within the EU internal electricity market is introduced (Renewable Portfolio Standard). There is no technology-specific promotion of cogeneration and no political restriction on the use of nuclear energy.

Since the mechanisms of allocating CO2-certificates are crucial for investment decisions, we compute a **Scenario IIa**, which is identical so Scenario II except that 100% of CO2-certificates are auctioned after 2012.

Scenario III: "Priority Environmental Targets"
This Scenario includes very ambitious emission reduction targets (-50% for Germany until 2030, -40% for the EU), 100% auctioning of CO2-certificates after 2012, enforced promotion of renewables by (periodically updated) feed-in tariffs yielding a share of renewables in electricity generation of 35% in Germany and the EU by 2030, an enforced promotion of cogeneration, and a phase-out of nuclear power.

Figure 1: Overview: Specification of Energy Policy Scenarios

		Scenario I	Scenario II / IIa	Scenario III
GHG Reduction Targets (*)				
DE	2010	-21%	-21%	-21%
	2030	-21%	-30%	-50%
EU	2010	-8%	-8%	-8%
	2030	-8%	-19%	-40%
Allocation Mechanism for CO2 certificates Post-Kyoto		Continued costless allocation based on fuel/technology specific benchmarks after 2012	Continued costless allocation based on fuel/technology specific benchmarks after 2012 (II); 100% Auctioning of CO2-certificates after 2012 (IIa)	100% Auctioning of CO2-certificates after 2012
Renewable Targets (#)		**Continued** Renewable Promotion	Market-based European-wide Promotion System for Renewables	**Enforced** Renewable Promotion
DE	2010	13%	13%	15%
	2030	30%	Market result	35%
EU	2010	17%	17%	22%
	2030	27%	27%	35%
Cogeneration		**Continued** Promotion of Cogeneration	Phase-out promotion of Cogeneration	**Enforced** Promotion of Cogeneration
Nuclear Power		Phase-out Nuclear	No political restriction	Phase-out Nuclear

(*) compared to 1990; (#) Share in Gross Electricity Consumption

3. Methodology

The scenarios are based on a fully integrated modelling approach including both the development of energy demand based on detailed analyses of industrial production processes, especially with high specific input of electricity, of the transport sector, applications of electricity in private households and residential and commercial sectors, as well as energy supply, with special emphasis on the power generation system.

The approach takes into account essential interactions both within the energy supply system and between the energy sector and the other sectors of the economy. These interdependences include:

- the direct effects of energy policies on costs and prices of electricity and their impact on energy demand;
- the indirect cost and price effects through the interdependence of sectoral production, including employment and income effects;
- demographic and economic developments, including autonomous and price-induced changes in energy efficiency;
- within the energy system: the interaction between heat and power markets via cogeneration in district heating, industrial and small scale applications;
- the repercussions of an increasing share of fluctuating, non-dispatchable electricity generation, especially wind power, on the conventional generation system, including stochastically derived reserve capacity and balancing power requirements and an explicit modelling of balancing energy markets;
- endogenous trans-border electricity exchange within the EU internal market.

In order to map these interactions, we combine the long-term multi-region energy optimization models CEEM (Cogeneration in European Electricity Markets), the long-term and high temporal resolution market model GEMS (German Electricity Market Simulation) of EWI, with the sectoral and macro-econometric models of EEFA. The energy models rely on an extensive database on existing power plants in Europe, including, among others, conversion efficiencies and technical life-times of individual plants. Given assumptions on fuel prices, investment costs and other technical-economic data of new plants, we compute investment dynamics in the power sector, generation by vintage, technology, and fuel, CO2-emissions, costs and prices of electricity.

It is important to note that (marginal cost based) electricity price formation in peak periods, when capacity constraints are binding, includes marginal capacity costs, thus covering full cost of new capacity in the long run. Electricity prices and investment needs in the power sector link the energy models of EWI and the macro-economic models of EEFA. The later include behavioural equations embedded in a consistent system of identities derived from the energy balances of the EU-25. Both the energy supply and the macroeconomic models are based on extensive databases, securing the practical relevance of scenario results. The macro-econometric models feed back price-dependent electricity demand to the energy models, thus yielding consistent energy and macroeconomic scenarios for Germany and the EU until 2030. Detailed descriptions of the EEFA models are included in Hillebrand (1997), for the energy market models of EWI see www.ewi.uni-koeln.de.

4. Preliminary Scenario Results

In this Section, we illustrate some preliminary results of Policy Scenario I regarding the electricity sector. Further results, including the demand side (industries, transportation, private households and other sectors) and other Scenarios will be included in spring 2007, as soon as available from this ongoing research.

Policy Scenario I

Regarding the electricity sector, an overall tendency in all scenarios is the gradual decrease in demand for base load power, due to an increased generation from renewables, especially onshore and offshore wind and biomass. In Scenario I, some 80 TWh electricity is generated from renewables in 2030 (Fig. 2).

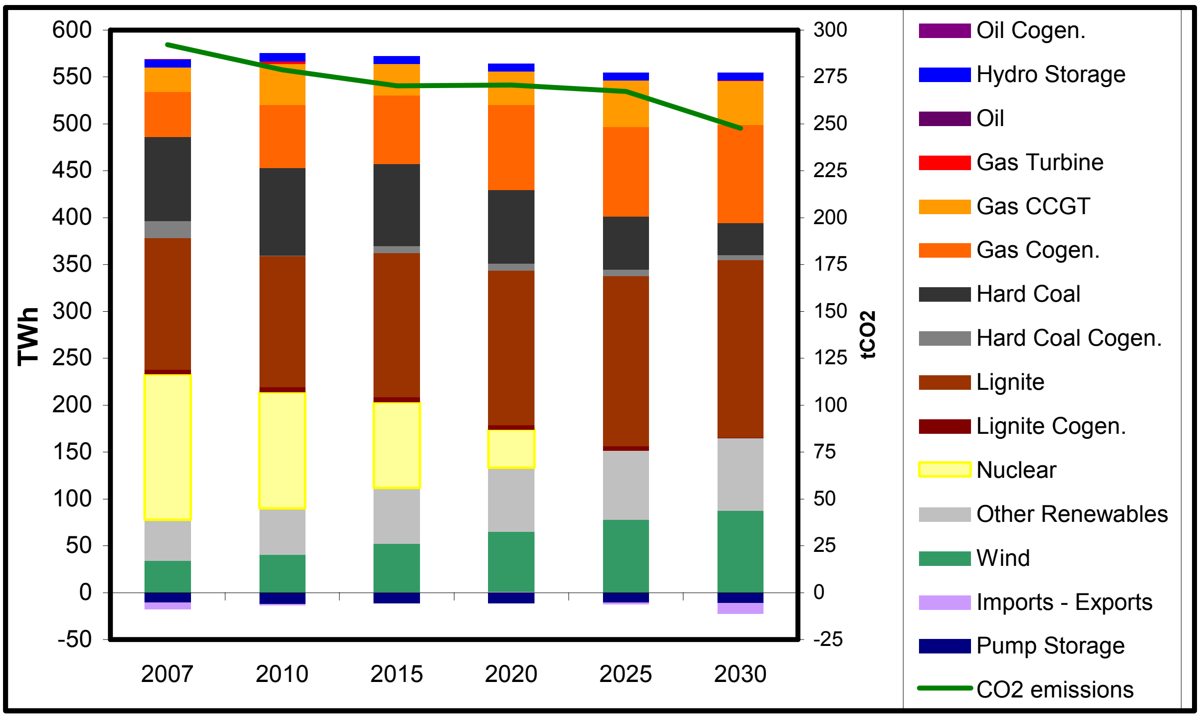
Nuclear power is phased out in Policy Scenario I according to current legislation, leaving no nuclear generation in 2025.

Gas-fired electricity generation is increasing based on CCGTs, and, more important, based on cogeneration in industry and district heating: While the underlying heat demand is stagnating (in industries) or decreasing (due to improved thermal insulation of buildings), co-generated power increases due to increased electricity-to-heat ratios of new gas-fired CHP plants compared to the replaced coal-fired plants installed in Germany in the 1970s and 80s.

The present production capacity of indigenous lignite in Germany will be maintained. No new coal mines will be opened, thus lignite production is limited to 50 Mio Hard Coal Units p.a. (in all Scenarios). In Scenario I, this capacity is fully utilized, leading to an increase in lignite-based electricity generation due to increased conversion efficiencies of modern lignite power plants.

Taken together, these developments in imply a slight decrease in power-related CO2-emissions in Germany until 2030 as indicated by the right axes in Fig. 2.

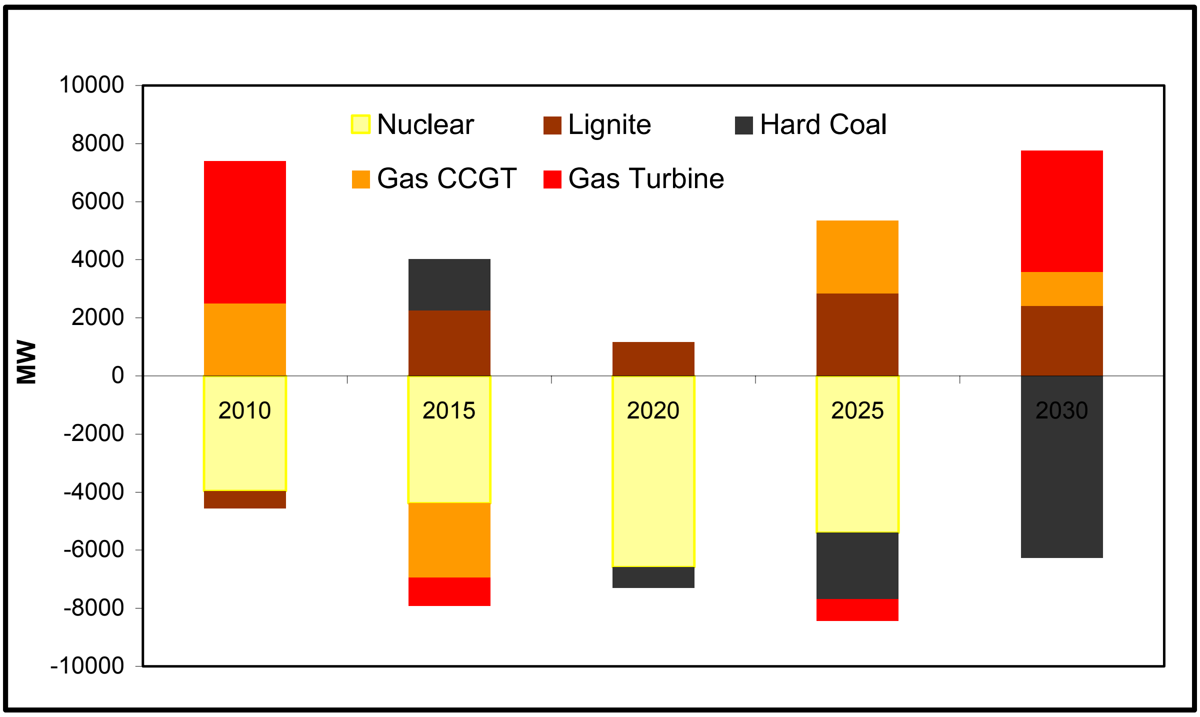
Figure 2: Electricity generation by fuel/technology, Germany (Scenario I)



The above developments result from a detailed modelling of market-driven capacity changes. In Fig. 3, we present net capacity changes in the competitive power market, i.e. capacity additions minus retirements by fuel/technology. Example: until 2015 (2011-2014) some 6700 MW hard coal plants are newly installed, 4900 MW retired, yielding a net change of installed hard coal-fired plants of +1800 MW.

Note that the depicted capacity changes relate to electricity-price dispatched plants only, and do not include CHP plants, which are operated mainly heat-controlled. Since the amount of cogenerated electricity increases, the electricity price-controlled market segment is shrinking: Fig 3 shows more capacity retired (negative) than added (positive). Retirements include mainly nuclear plants, additions mainly lignite-fired and gas-fired plants.

Figure 3: Net Capacity Changes (Additions – Retirements) by fuel/technology, Germany: Scenario I



These capacity changes result in a development of installed capacities and their utilization rates as shown in Figs. 4 and 5.

Regarding capacities and their utilization, a number of points are noteworthy. First, gas turbines are utilized primarily to meet the demand of (positive and negative) regulating power, balancing the increasing stochastic feed-in of wind energy. Accordingly, the revenues of those plants mainly stem from (energy and capacity) payments on the regulating power markets (which are explicitly modelled). Second, the capacity credit of wind power plants decreases with increasing share of wind and falls below 5% of installed wind plant capacity in 2030; this is taken into account in the demand for secured capacity, to which (besides GTs) hard coal fired plants contribute, leading to a reduction of utilization rates of those plants. Third, the utilization rates in Fig. 5 are averages over the respective fuels/technologies; they are higher for newly installed plants and decrease for older plants with lower conversion efficiencies. Finally, the average utilization of wind power plants increases, reflecting the increased share of plants with higher full load hours off-shore.

Figure 4: Generation capacities by fuel/technology, Germany (Scenario I)

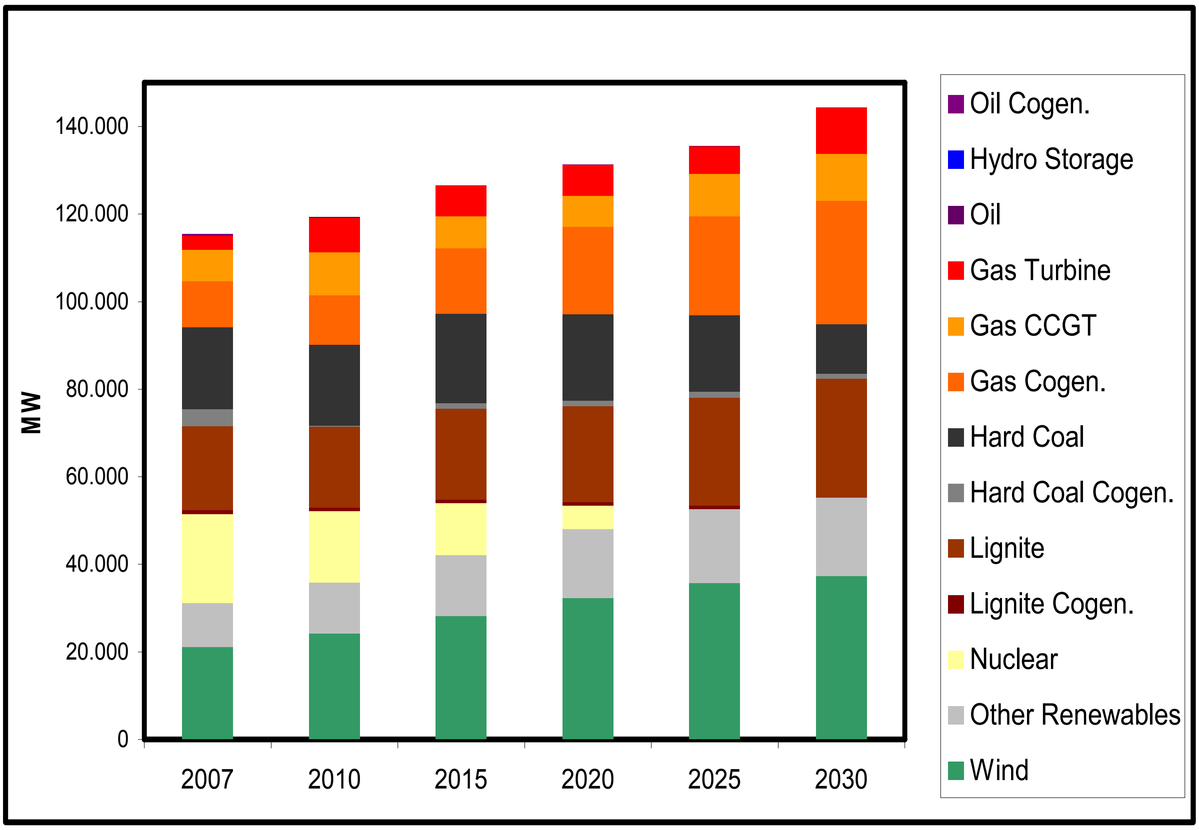
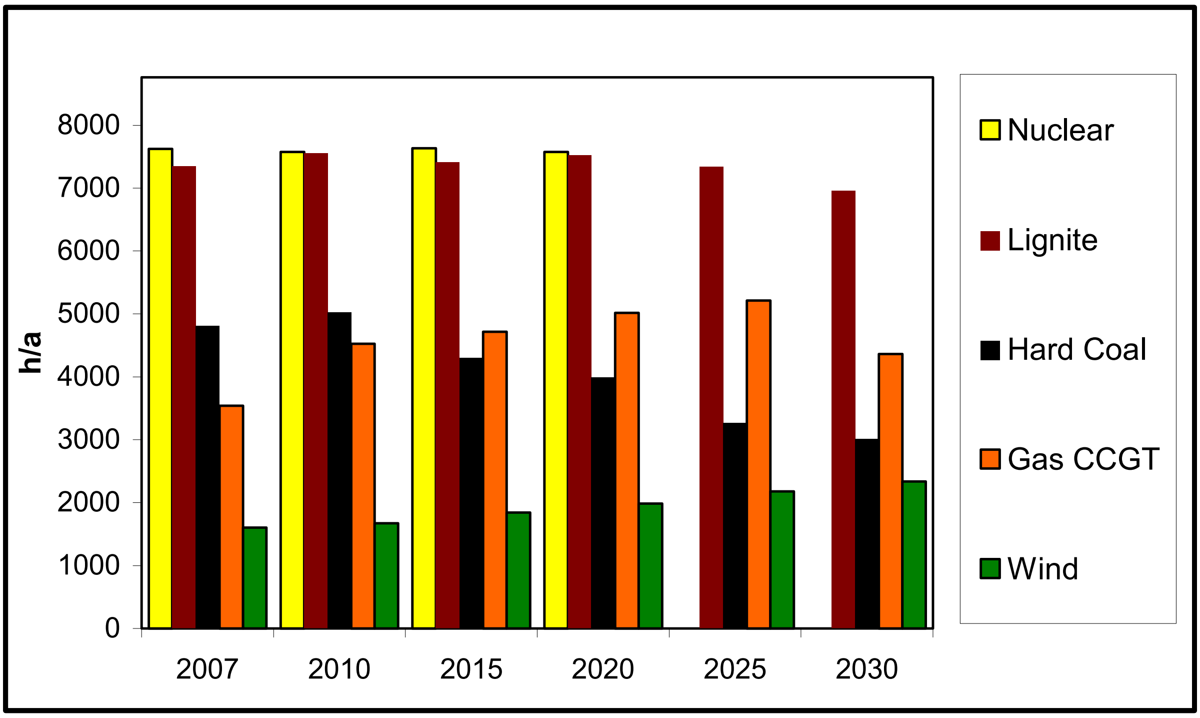


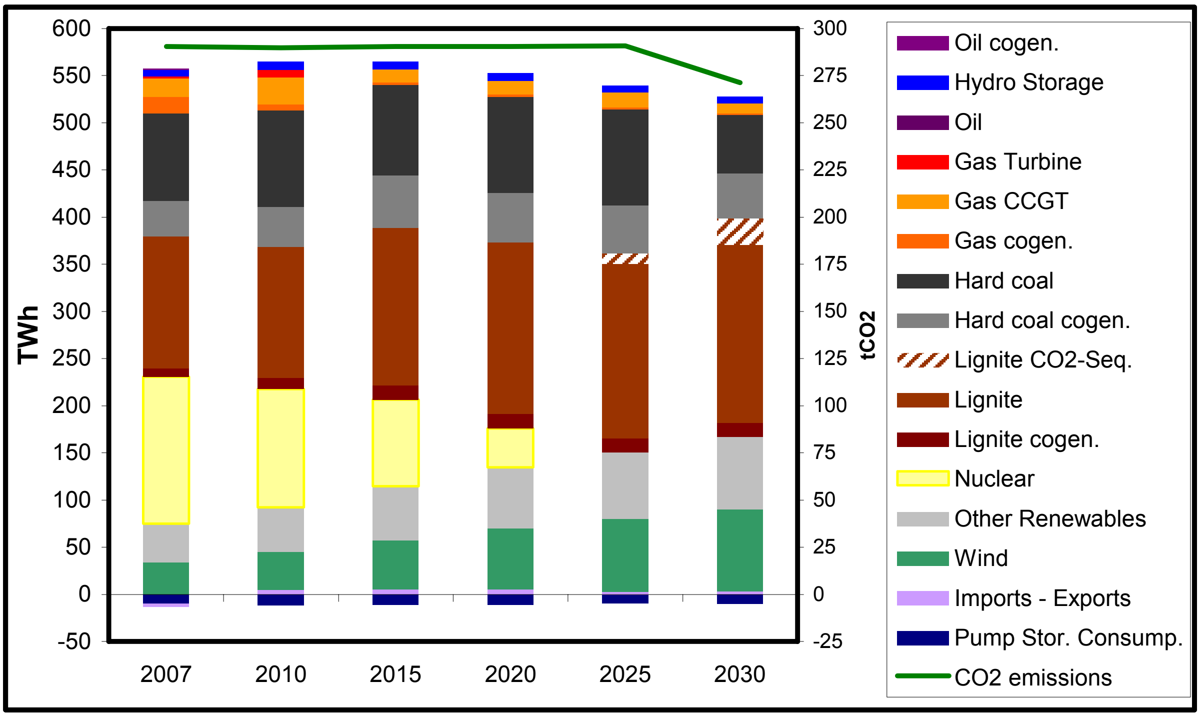
Figure 5: Capacity Utilization by fuel/technology until 2030, Germany (Scenario I)



Sensitivity to Policy Scenario I: Higher Energy Prices

Since fuel prices are crucial to investment decisions especially in the power sector, we analyse all scenarios under higher energy prices. In those sensitivity analyses, the price for crude oil in 2030 is 50% higher than in the base case (75$(2005)/bbl in 2030 compared to 50 $(2005)/bbl in the base case). The gas price is assumed to remain coupled to the oil price, resulting in a gas price incl. transportation of 24€(2005)/MWh in 2030, compared to 16€(2005)/MWh in the base case. Prices for hard coal and lignite are unchanged, thus covering the relevant spread between gas and coal prices by Scenario I and sensitivity. (Detailed assumptions on energy prices will be included in a later version of this paper.) The resulting energy mix in the electricity sector under higher energy prices is depicted in Fig. 6.

Figure 6: Electricity generation by fuel/technology, Germany: Scenario I – Higher Energy Prices



Not unexpectedly, higher energy prices, especially higher gas prices favour hard coal and lignite in power generation. A feature of this scenario, at the chosen assumptions regarding investment costs and conversion efficiencies of CO2-sequestration, is the economic viability of this technological option based on indigenous lignite: Until 2025 some 2GW, and until 2025 another 2GW of lignite sequestration plants are phased in the German plant mix. Nevertheless, CO2 emissions in power generation can be reduced only slightly until 2030 in this Scenario.

The paper will be updated and further results included as soon as available from this ongoing research:

- *Policy Scenario II and Sensitivity 'Higher Energy Prices'*
- *Policy Scenario IIa (Post Kyoto Auctioning of CO2-certificates instead of continued costless allocation based on BAT benchmarks) and Energy Price Sensitivity*
- *Policy Scenario III and Energy Price Sensitivity*

The scenarios will be evaluated based on the following criteria:

- *energy mix and import dependence*
- *costs and prices of energy*
- *emissions*
- *sectoral production and employment*