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Englische Kurzfassung

Executive Summary

Prices of oil and other fossil fuels on global markets have reached a high level in recent years. These levels were not able to be reproduced on the basis of scenarios and prognoses that have been published in the past. New scenarios, based on higher energy price trajectories have appeared only recently (EIA 2006b; EWI/Prognos 2006; IEA 2006). However, the future role of various energy carriers and technologies in energy-economic scenarios will greatly depend on the level of energy prices. This is particularly true of scenarios that are developed with the help of energy models. Therefore, an analysis of the impact of high energy prices on long-term scenarios for Germany has been undertaken. For this purpose the German Federal Environment Agency (Umweltbundesamt) contracted Öko-Institut, the German Institute for Economic Research (DIW) and Forschungszentrum Jülich to develop a series of three energy price scenarios has been developed which constitutes the basis for the analysis using two different models. Whilst an optimisation of the whole energy system in Germany was carried out using the IKARUS energy systems model, the ELIAS model was used to analyse the trends emerging from microeconomic investment decisions in the electricity industry.

Energy Price Scenarios

In 2003, the price of crude oil started to increase sharply and reached about 80 US $/bbl in the summer of 2006. In nominal terms this constituted a new historical price peak. If corrected by price increases arising from general inflation, the price was not as high as that at the end of the 1970s. Accounting for productivity and respective income increases during the last 35 years, the increase of working time needed to buy one barrel of oil is still moderate. Higher energy efficiency additionally dampened the impact of higher oil prices. Macroeconomic effects due to the oil price shock were also dependent on the behaviour of central banks. They did not react with sharp interest rate increases on this occasion, because the inflation path did not lead to a wage price spiral. Central banks - especially in Japan and the USA - may even have contributed to the recent oil price shock by means of their low interest rate policy. The created liquidity thus moderated the crisis of the stock markets after 2000. Therefore, three years of high prices did not initiate a worldwide recession as happened after the price shock at the end of the 1970s. Economic growth remained high, especially in Asia and the USA. In Europe - even in Germany - growth recovered after five years of stagnation in 2006. This dampened the effects of high oil prices on economic growth and on oil demand worldwide. If oil supply growth really lagged behind demand, oil prices would temporarily increase until a level is reached which triggers the reduction of oil demand that would be necessary to balance global demand and supply – if necessary by a recession. Such a development has not taken place to date. After a peak in the summer of 2006, the oil price dropped to below 60 US $/bbl in the autumn of 2006, then recovered and dropped again substantially at the end of the year. One reason for this may be that the US central bank raised interest rates and that economic growth in the United States has started to slow down. To prevent a further drop of prices, OPEC countries reduced their production for the first time since the autumn of 2003 (by 1.2 mbd) and announced that they would reduce it further in February 2007 (by 0.5 mbd). Nevertheless, the prices continued to fall at the beginning of 2007.

More remarkable than the moderate effect of past oil price increases on world economic growth has been its effect on long-term oil price forecasts. Before the price started to explode at the end of 2003, the aim of the OPEC was to stabilise the oil price at about 25 US $/bbl. For most analysts this was an ambitious target, since the marginal costs of oil production and the benchmark of oil companies for new projects was far below that level. Past predictions by some geologists that oil production would peak some years from now or had just peaked were not taken seriously by most policy makers. This has changed as a result of the price shock. Now most analysts and politicians interpret the oil price shock not as a temporarily peak of a long-term price fluctuation as in the past, but as a signal of a fundamental change in the oil markets induced by the higher than projected demand (especially by China) and a limited supply (due to a lack of sufficient resources or investments in major producer countries). By the end of 2005, the EIA changed its price assumptions dramatically; in 2006 the IEA did the same. The reasons offered by both the EIA and IEA to explain these changes in their price assumptions were investments in oil exploration and production facilities being lower than previously assumed, and were not changed assumptions of recoverable resources. In its world energy outlook of 2006, the IEA projects crude oil prices of about 60 US $\$_{2005}$ in 2030.

There is no certainty about the development of oil prices in the coming months and years or as to whether they will rise or fall moderately or sharply. Our knowledge of technological and political development, elasticities of demand during different stages of economic development, the amount of recoverable resources, the long-term effectiveness of OPEC and, last but not least, the interdependence of spot and future markets make it nearly impossible to predict oil prices with an appropriate degree of accuracy. Therefore, it is more helpful to refrain from making such predictions. If assumptions about oil prices are necessary, scenarios of possible developments can be sketched.

High oil and energy prices may have important effects on the level and structure (by energy carriers) of energy consumption and production and thus on CO_2 emissions. To explore these effects in detail we sketched as a first step in this study three possible price scenarios: a reference scenario with a moderate price development, a scenario with high prices and a scenario with a sharp price peak. As we assume that oil will remain the most important energy carrier worldwide up to 2030 and oil prices will therefore remain the best indicator of the world energy situation, our scenarios start with assumptions of oil price developments (in US $/bbl) which are then translated into import and consumer prices for crude oil and energy products in Germany in Euro. Based on crude oil prices in US dollars, the development of the cross-border import prices in Euro for crude oil, natural gas, hard coal and mineral oil products were determined from an analysis for the last 30-35 years of currency relations between US dollars and Euro (1.1 US$/€) and price relations of mineral oil products, natural gas and hard coal as compared to crude oil. This analysis justifies the simple assumption of long-term constant relations for the future.

Table S-1 Scenarios of crude oil price developments up to 2030 in US $\$_{2000}$/bbl

Scenario	2000	2005	2010	2015	2020	2025	2030
Reference	28.4	48.7	28.0	30.0	32.0	34.0	37.0
High prices	28.4	48.7	54.1	63.7	73.3	77.9	82.5
Spike	28.4	48.7	105.0	105.0	62.0	34.0	37.0

Sources: EIA 2006b; EWI/Prognos 2005; Goldman Sachs 2005

As a reference, the moderate price development according to EWI/Prognos is used (EWI/Prognos 2005). EWI/Prognos assumes that overall low cost conventional and unconventional oil reserves and resources are ample enough to dampen oil prices until 2030. Accordingly, they assume that crude oil prices will fall to 28 US $\$_{2000}$/bbl by 2010 and will only moderately increase thereafter to 37 US $\$_{2000}$/bbl in 2030. Nevertheless, even if enough oil reserves and resources exist, the question remains as to whether enough capital will be invested to exploit that potential so that supply and demand will be balanced in the period up to 2030.

Political instability in important oil producer countries (especially in Nigeria, Iraq, Iran and Venezuela), and also a growing resource nationalism in other countries (e.g. Russia) could result in lower investments in the oil sector than were assumed some years ago. The result could be an ongoing supply shortage as well as high oil prices and further increases therein – as assumed in the high price scenario (EIA 2006a; EIA 2006b).

A political crisis in an important oil producer country could drive prices even higher than is assumed in the high price scenario. Goldman Sachs sketched such a spike scenario (Goldman Sachs 2005). In this scenario it is assumed that prices rise until demand is reduced so that capacity reserves in oil production and in the refinery sector result. We assume that in such a case the high risk premiums incorporated in oil prices today will shrink to a normal level and oil prices will fall to the moderate price level in the reference scenario.

Analysis using the IKARUS Energy Systems Model

Model Description

The IKARUS bottom-up model is deployed in our research project in order to examine the effects of different price scenarios The IKARUS model is a time-step dynamical linear optimisation model which maps the energy system of Germany in terms of cross-linked processes from primary energy supply to energy services. A large number of technological options are included along with the corresponding emissions and costs as well as possible networks of energy fluxes. In addition, general political set-ups are considered.

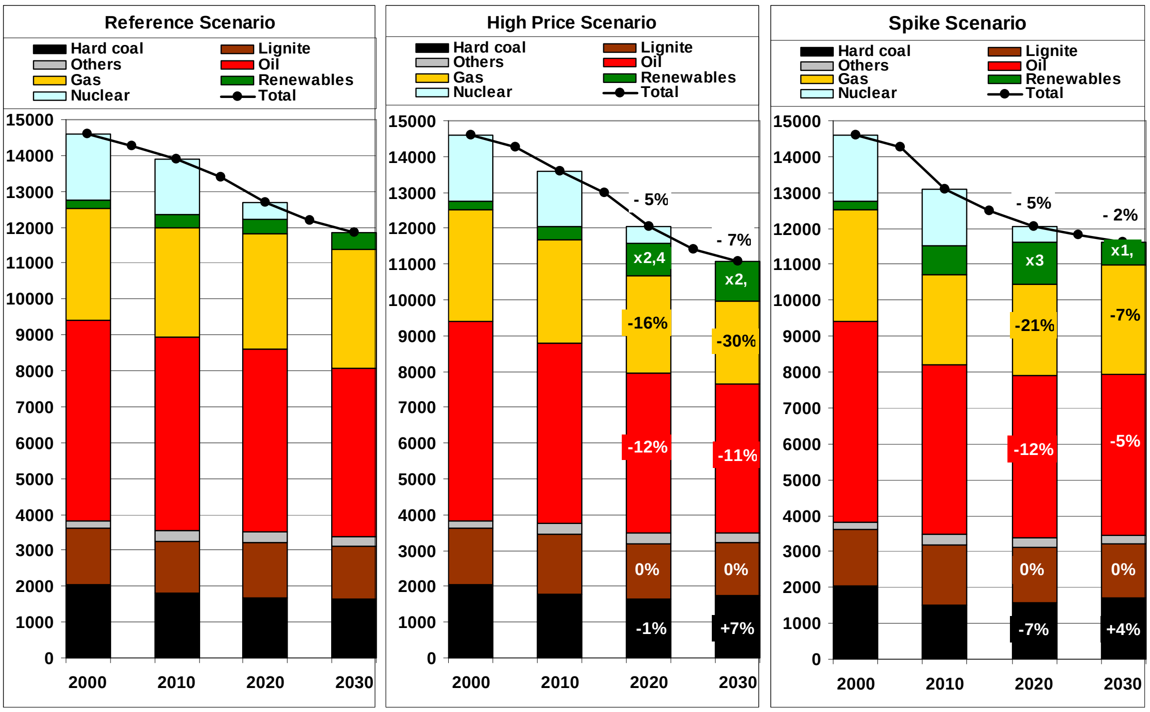
Within the model, the energy system is mapped in such a way that the demands for energy services are fulfilled; equilibria are formed on various intermediate conversion levels (partial equilibrium model). Its time horizon is divided into five-year intervals. Each time interval is optimised by taking into account the past stock change resulting from all previous periods in a separate dynamic program module. Thus, the model does not follow a perfect foresight approach, where the model in principle “knows” all the future parameters and boundary conditions. Perfect foresight models can react on exogenously given future changes in advance of these changes taking place (e.g. prices of energy carriers, climate gas reduction policy). Well-known energy systems models that employ a perfect foresight optimisation approach are MARKAL and MESSAGE. The time-step model is, however, myopic and does not take into account future changes in each optimisation step. It is thus a model in which prognosis and projection have a more realistic character. Due to its myopic character, the model is well-suited to examine reactions on various energy price scenarios, including sudden changes like a price shock.

Besides limitations on quantities of imported energy carriers like coal, other restrictions based on domestic potentials for fossil and renewable energy carriers and the political framework set by the Federal Government form part of the model (e.g. the phase-out of nuclear energy). The transport sector has received special attention in our analysis and has therefore been treated differently. In contrast to the other sectors, fuel taxes at the current level have been included in the transport sector to account for the correct relation of consumer and import prices. In addition, an elastic demand for transport has been incorporated.

Scenario Results

In the scenario analyses using the IKARUS model, high increases in the prices of mineral oil, natural gas and imported hard coal lead to a significant reduction in primary energy consumption (see Figure S-1). Whilst primary energy consumption decreases by 19 % in the period from 2000 to 2030 in the reference price scenario, it drops by 24 % (high price scenario) and 20 % (spike scenario) in the price scenarios within the same time period. In comparison to the reference price scenario, this corresponds to a reduction of about 7 % and 2 % respectively. The decrease in the reference scenario is due to socio-economic data (e.g. population decline), sector-specific structural change in the industry and in the commercial sector as well as autonomous technological progress that leads to an increase in energy efficiency. However, there is also a systematic effect due to the accounting of TPES according to the physical energy content method. The phase-out of nuclear power and the simultaneous increase of the share of renewables result in a reduction of TPES. The differences between the two price scenarios can above all be traced back to the relaxation effect in the spike scenario, whereby the implementation of measures which conserve primary energy markedly decreases following the subsidence of the price shock after 2015. The degree of freedom for adaptation and in particular for the observed relaxation effects depends largely on technical lifetimes which differ for the different sectors.

Figure S-1 Total primary energy supply (PJ) in the reference, high price and spike scenario



Sources: Calculations Forschungszentrum Jülich

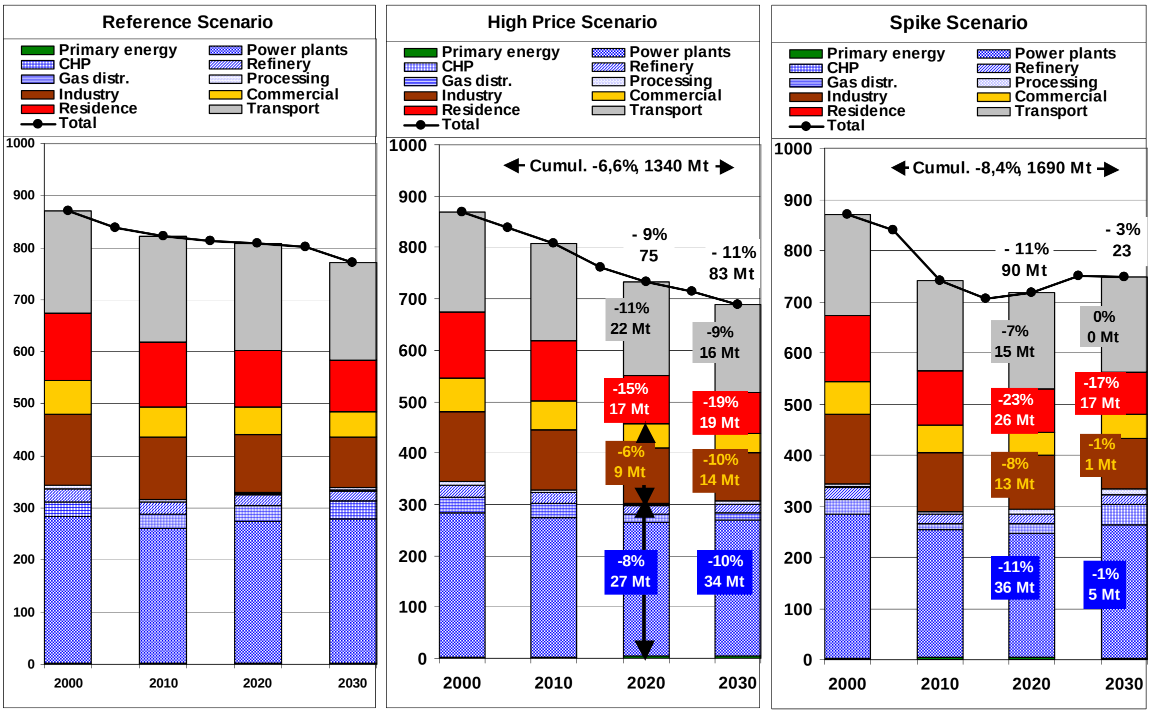
In comparison to the reference scenario, there is a significantly reduced application of oil products and especially natural gas (up to -30 %) in the price scenarios. The use of domestic lignite temporary increases with increasing import prices. However, at the end of the time horizon it equals the level of the reference scenario again, as a result of the limited availability of lignite whose potential is already fully utilised in the reference scenario in 2030. In spite of price increases, the use of hard coal rises up to 7 % in the period 2030. Even domestic hard coal, which is currently not competitive and is highly subsidised, is used again to a limited extent in the price scenarios. An interesting feature of the price scenarios is that domestic lignite is not only used in the conversion sector for electricity production, but also for coal liquefaction, serving as a backstop technology after 2010, corresponding to a break-even price of crude oil of approximately 54 US $\$_{2000}$/bbl. However, the share of coal liquefaction remains relatively small (about 90 PJ of lignite corresponding to about 1 million tons of oil products).

An important aspect of higher prices for fossil energy carriers is the impact on emissions, in particular carbon dioxide. In the reference price scenario CO_2 emissions fall by almost 100 million tons per year in the period from 2000 to 2030 (this corresponds to a reduction of about 11 %). The following effects on the abatement of CO_2 emissions result from the scenario analyses using the IKARUS model (see Figure S-2):

- The CO_2 emissions in the industry sector are generally inelastic with regard to both energy price levels.
- High energy prices produce significant emission abatements, above all in the residential, transport and commercial sectors.
- In contrast, high energy prices in the electricity production sector only produce comparatively low CO_2 abatements. These can predominantly be attributed to the systematic increase in electricity production from renewable energy sources (mainly wind and biomass), although they are partly compensated by an increasing trend towards coal-fired electricity production. Electricity production from natural gas is strongly reduced at the same time.
- High energy prices lead to an increase in the share of renewable energies within TPES (see Figure S-1). In the high price scenario, this enhancement is in particular the result of a substantial use of biomass and wind, and, to a lesser extent, an increase in biofuels in the transport sector. In the spike scenario, the use of renewable energy carriers triples in comparison to the reference scenario and reaches a level of about 1100 PJ in the period to 2015. The energetic use of biomass (mainly in heating and CHP plants) plays an important role in this scenario.

The trends that vary between sectors also need to be emphasised. High energy prices lead to significant emission abatements, above all in the residential, transport and commercial sectors. In the residential and commercial sectors this reduction of CO_2 emissions is due to technical measures only; in the transport sector it includes effects from an elastic demand as well. It should be noted that the two high price alternatives affect measures in very different ways over time. The annual emission savings in 2030 are markedly higher in the high price scenario than in the spike scenario. Greater emission savings are, however, temporarily achieved in the spike scenario; cumulatively, these lead to a significantly higher reduction of CO_2 emissions in the spike scenario (1690 Mt) than in the high price scenario (1340 Mt), since they are realised sooner.

Figure S-2 *CO_2 emissions (Mt) in the reference, high price and spike scenario*

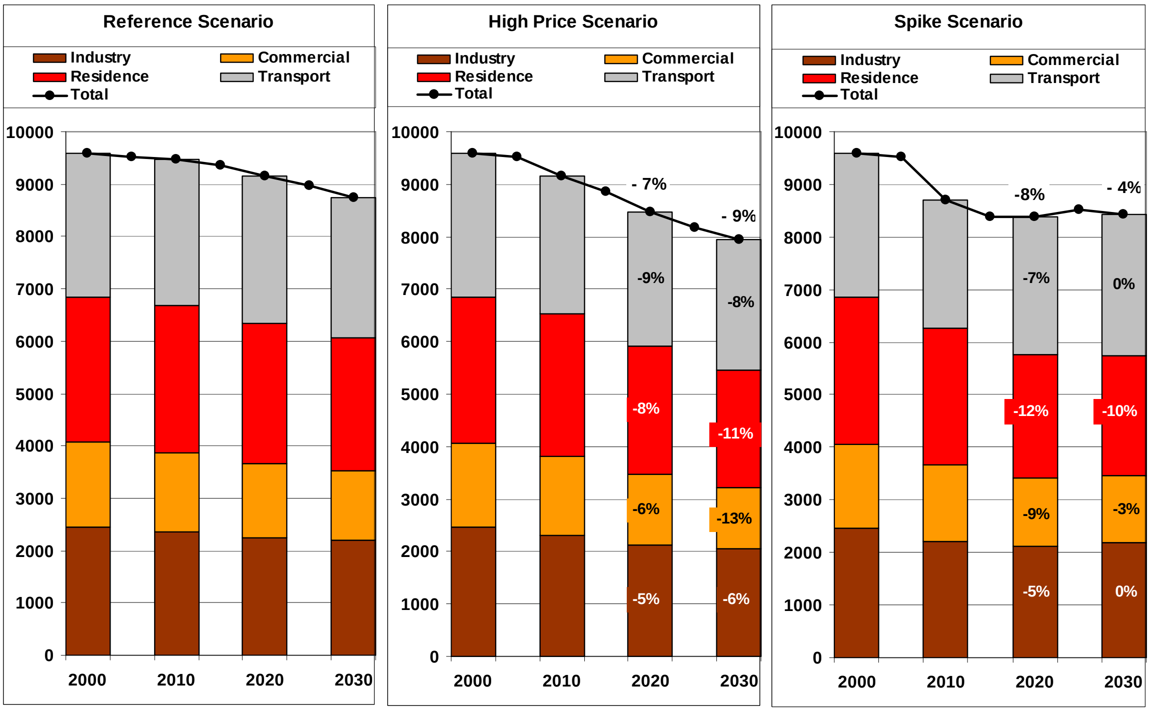


Source: *Calculations Forschungszentrum Jülich*

The energy savings in the end-use sectors are somewhat higher (up to -10 %) than for the primary energy consumption (up to -7 %) in the two price scenarios (see Figure S-3). In particular, the use of natural gas and oil products decreases as a result of the higher price levels.

The contribution of each sector to final energy savings shows sizeable differences. In general the residential sector contributes the most to these savings followed by the transport, commercial and industry sectors. Again, the reduction of final energy consumption is due to technical measures and in addition an elastic demand for transport. The lifetime of technical measures is an important criterion of whether the energy saving will persist in the long run or whether corresponding relaxation effects will occur. In the spike scenario, the final energy consumption of industry and transport adjusts to the reference scenario again up to 2030 on the one hand. On the other hand, the savings remain preserved in the household sector and partly so in the commercial sector. This is mainly due to improvements to the thermal insulation of buildings whose technical lifetimes are beyond 30 years and show therefore a corresponding long-term effect.

Figure S-3 *Final energy consumption (PJ) in the reference, high price and spike scenario*



Source: *Calculations Forschungszentrum Jülich*

The additional thermal savings in the residential sector lead to a decrease in useful energy demand of about 150 PJ in the high price scenario in 2030. This corresponds to a decline of approximately 10 % compared to the reference scenario. In the spike scenario, the reduction of useful energy consumption in the residential sector occurs more quickly and its impact on the demand for useful energy is also greater (–170 PJ in 2030).

Analysis using the ELIAS Electricity Sector Model

Complementary to the model analysis in the IKARUS model, a sector analysis of electricity production was undertaken using the ELIAS model. ELIAS is based on microeconomic considerations determining the investments of economic subjects. These include, for instance, the implementation of the emissions trading scheme or the German Renewable Energy Act (EEG).

Model Description

The ELIAS (Electricity Investment Analysis) model focuses on the electricity sector, since this sector contributes substantially to overall emissions and major investments are necessary in the years ahead due to the nuclear phase-out as well as the decommissioning of old power plants. The power sector is characterised by a long-living capital stock; today’s investments will significantly influence future emissions. ELIAS allows for the evaluation of political instruments which influence the future technology mix in the power sector. Political instruments can be represented in great detail to enable the comparison of diverse design options, e.g. different allocation rules within the emissions trading scheme.

The ELIAS model calculates the amount of new capacity to be added in the electricity sector on the basis of a stock-exchange approach, identifying power plants which will come to the end of their useful life and the expected development of the electricity demand. The ensuing capacity gap is covered by investment in new power plants. It is assumed that the economic subjects invest in the technologies with the lowest average electricity production costs. The calculation of electricity production costs takes into account fixed and variable costs, fuel prices as well as costs and benefits resulting from political instruments such as the emissions trading scheme or the German CHP Act (KWKG).

In the real world, investment is not limited to the one cheapest technology; to avoid the so-called penny-switching effect, the construction of power plants that do not constitute the cheapest option are also contained within the model, with decreasing capacities depending on the electricity production cost difference to the cheapest option. The construction of certain technologies may be restricted within the model. This is the case, for example, in hydro energy or lignite mining, which are limited by available resources. It is assumed that no new nuclear power plants will be built in Germany.

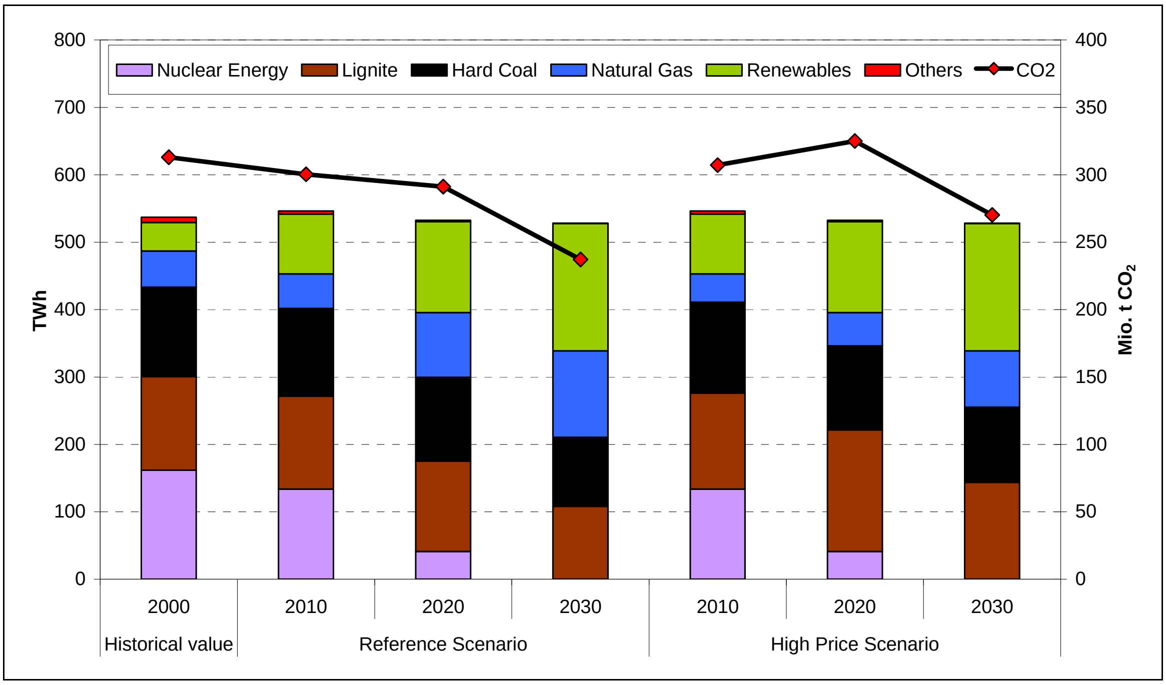
The reference and the high price scenarios have been modelled using the ELIAS model. Since ELIAS is a model based on *perfect foresight*, the spike was not modelled since it would not lead to meaningful results.

Scenario Results

It is assumed that the systematic increase of electricity production from renewable energies will follow the goals discussed (politically) up to now and that the corresponding support measures are adapted in the course of time to increase the electricity production from renewable energies to almost 190 TWh in 2030. The development of CO_2 emissions in all scenarios is largely characterised by this increase of renewables in combination with the nuclear phase-out.

- In the reference price scenario when it is assumed that allocation to new entrants continues according to the approach adopted in the first trading period (2005-2007) in Germany in the allocation of carbon credits (fuel-specific allocation and long-term allocation guarantees), CO_2 emissions decrease relatively steadily over time. In 2030, the level of CO_2 emissions is around 75 million tons under the value of 2000 (see Figure S- 4).
- In the high price scenario, CO_2 emissions decline by around 6 million tons by 2010, rising again by 18 million tons by 2020 – caused by the phasing-out of nuclear energy and the diminishing attractiveness of natural gas-fired electricity production – and declining once again after that by around 55 million tons in the period up to 2030 (this corresponds to an overall emission reduction of 43 million t CO_2 in comparison to 2000).

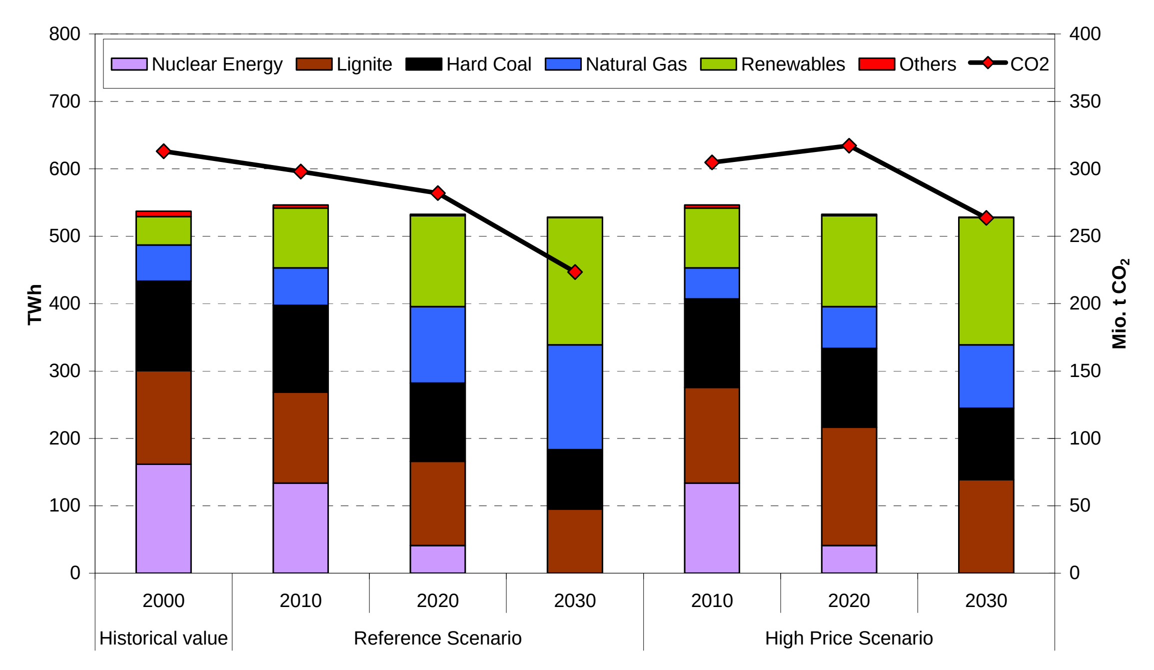
Figure S- 4 *Net electricity generation and CO_2 emissions for the reference and high price scenario assuming current ETS allocation provisions*



Source: *Calculations Öko-Institut*

- In the reference price scenario when an ideal type of emissions trading scheme is assumed in which emission allowances for new entrants is auctioned, CO_2 emissions fall by around 90 million t CO_2 in the period up to 2030 vis-à-vis the year 2000 (see Figure S-5).
- In the high price scenario emission reductions are significantly lower even if auctioning is assumed (the reduction is – compared to the scenario with reference prices and auctioning - roughly 50 Mt CO_2 lower) and comparable to the high price scenario under current allocation rules.

Figure S-5 *Net electricity generation and CO_2 emissions for the reference and high price scenario assuming an ETS with full auctioning*



Source: *Calculations Öko-Institut*

Changes in the levels of emissions are essentially due to the economic situation of coal- and natural gas-fired electricity production on the one hand and the economic attractiveness of cogeneration on the other hand.

In the high price scenarios, the economic attractiveness of natural gas-fired electricity production declines markedly. Electricity production from natural gas doubles in the reference price scenario when the allocation model is applied that is currently used, and triples when auctioning is introduced. Yet natural gas-fired electricity production only slightly increases in the high price scenarios, even when full pricing of CO_2 emissions takes place.

In contrast, the share of electricity produced via CHP increases when energy prices rise and full CO_2 pricing occurs; its share in terms of the total electricity production expands to significantly more than 20 % in 2030.

Against the background of the fact that the result structures of the IKARUS model calculations (for the sub-segment of electricity production) are partly very similar to, and partly diverge markedly from, the ELIAS calculations with regard to the basic alternatives, a series of sensitivity calculations were carried out to reduce such differences and to quantify the effect of different parameters on the results.

The first sensitivity analysis for the purpose of the ELIAS model calculations addresses the differences in imputed interest rates. Whilst an entitlement to an interest rate of 10 % or more must be applied in microeconomic analyses, macroeconomic model calculations are based on imputed interest rates of around 5 %. Variations of these parameters lead to deviant results in the range of 10 million t CO_2 in 2030.

A second sensitivity analysis concerns the development of electricity production from renewable energies, when that production is not exogenously determined, but rather subordinated to microeconomic considerations, of which the support mechanism of the German Renewable Energy Act (EEG) continues to be the most important general condition. Given that EEG compensation rates are orientated to the costs of electricity production from renewable energies, there is only a marginal difference in such an approach between the total level of electricity production from renewable energies in the reference price scenario and the high price scenario, when the CO_2 costs of new entrants - as in the current German allocation model - are largely ignored in investment decisions. This situation is fundamentally changed when the attractiveness of investments in new fossil-fuelled power stations is significantly diminished due to full CO_2 pricing. The production level of regenerative power plants significantly increases as a result.

A third sensitivity analysis focuses on the technological parameters used. Therefore the parameters used in the model IKARUS were used in the model ELIAS. We could observe that the share of CHP projected using ELIAS were higher than forecasted by the IKARUS model even when the parameters of IKARUS power plants were used in ELIAS. Moreover the share of natural gas in overall power production was higher; this can partly be attributed to the different treatment of CHP as well because in ELIAS CHP benefits of a bonus corresponding to the amount of heat sold. This bonus can partly compensate the rising costs for energy carriers. These systematic differences are due to the different model philosophies. The resulting CO_2-emissions are nevertheless at a comparable level in 2030.

In contrast to the housing and transport sector high energy prices do not lead to significant reduction of GHG emissions in the power sector. In general, CO_2 emissions are higher in the high energy case than in the reference scenario, but a reduction in comparison with the base year is still achieved as a result of the increase of renewables and CHP in power production. By contrast, the power sector reacts very sensitively to the pricing of CO_2 emissions; especially in the reference price scenario a change in the design of the emissions trading scheme (auctioning in the place of fuel specific allocation) can lead to a substantial reduction of emissions.