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The German “Energiewende“ – A Scenario Analysis

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The German “Energiewende” – A Scenario Analysis

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Abstract
Germany aims at transforming its energy system towards a sustainable system relying on energy-saving technologies and renewable energy sources. The fundament of this transformation is the Energy Concept of the Federal Government from 2010, which was updated 2011 as a reaction on the catastrophe in Fukushima. In this long abstract we analyse the impacts on the energy system with regard to technical developments and system costs. Therefore we employ the linear, technology-orientated bottom-up optimization model IKARUS.

Keywords

Contribution to
International Energy Workshop 2012 (IEW 2012), Cape Town, South Africa
I  The German “Energiewende”

With adopting the “Energy Concept for an Environmentally Sound, Reliable and Affordable Energy Supply” in September 2010, the Federal Government defined a new path to Germany’s energy system of the future [Federal Government of Germany, 2010]. A powerful driver was the political will to drastically reduce greenhouse gas (GHG) emissions. The conception in particular moved energy efficiency and savings as well as renewable energy sources in the focus of Germany’s energy policy. Another important aspect was the decision to extend the operation of nuclear power plants by an average of 12 years. By this means, nuclear power was supposed to play the role of a bridging technology towards an energy future relying on renewable energy sources.

The catastrophe in Fukushima on the 11th of March 2011 impressively made aware of the residual risk of nuclear power plants. Therefore, the German government reconsidered the role of nuclear power within the Energy Concept [Federal Government of Germany, 2011b]. As a first reaction a security check was announced, the seven oldest nuclear power plants and “Krümmel” were decommissioned and the extension of operation of the other nuclear power plants was suspended (moratorium).

Table 1: Major Goals of the German Energy Concept

<table>
<thead>
<tr>
<th>Goal</th>
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<tbody>
<tr>
<td>Phase out of nuclear energy until the end of 2022</td>
</tr>
<tr>
<td>Reduction of GHG emissions by 40% until 2020, 55% until 2035 and at least 80% until 2050 compared to the levels of 1990</td>
</tr>
<tr>
<td>Total primary energy supply (TPES) cut into halves by 2050</td>
</tr>
<tr>
<td>Share of renewables (RES) in TPES at least 30% by 2030</td>
</tr>
<tr>
<td>Electric power consumption reduced by 10% until 2020</td>
</tr>
<tr>
<td>Share of RES in electricity generation 50% by 2030 (80% by 2050)</td>
</tr>
<tr>
<td>Space heat demand of building stock reduced by 20% until 2020</td>
</tr>
<tr>
<td>Share of RES in final demand of the transport sector 10% by 2020</td>
</tr>
<tr>
<td>1 million electric vehicles until 2020, 6 million electric vehicles until 2030</td>
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</table>


On the 6th of June 2011 Germany changed the Atomic Energy Act and adopted decisions on the phase out of nuclear power until the end of 2022 [Federal Government of Germany, 2011a]. Nevertheless, most of the measures and goals formulated in the Energy Concept from 2010 – with the exception of the role of nuclear power - still
remain the same. The most important goals of the current German energy policy resulting from the described “Energiewende” are listed in Table 1.

II The Energy Systems Model IKARUS

In order to examine the interaction of the numerous political targets of the German Energy Concept, we employ the bottom-up model IKARUS [Martinsen, 2003, Martinsen, 2006]. The IKARUS model is a time-step dynamical linear optimization model mapping the energy system of the Federal Republic of Germany in the form of cross-linked processes from primary energy supply to energy services (Figure 1).

Figure 1: Structure of Energy Systems the IKARUS Model

All relevant sectors with a detailed representation of the technological options are included, characterized by their corresponding specific emissions and costs as well as possible networks of energy fluxes. Demands for energy services are the driving forces of the model, and equilibria are formed on various intermediate conversion levels (partial equilibrium model). The model’s time horizon extends to 2050 and is divided into 5-year intervals. Each time interval is optimized by itself, taking into account past events by the heritage due to results from all previous periods in a separate dynamic program module. In contrast to the more common class of perfect-foresight energy systems models, such as MARKAL [Fishbone, 1983, Loulou, 2004] or TIMES [Loulou, 2005], the time-step model is myopic and does not take into ac-
count future changes in each optimization step. It is therefore a model with a more realistic character of prognosis and projection.

III  Basic Assumptions and Calculated Scenarios

The time horizon will be restricted to 2030. After 2030 the targets of the energy concept are not very precise and therefore difficult to map in an energy model. Although quite different paths are considered, all scenarios share some basic assumptions:

As far as economic development is concerned, a gross domestic product (GDP) growth of 1.4%/y is assumed. Accordingly, the evolution of the industrial gross value added shows a real increase in all industrial sectors, however, to a varied extent in different industries. We assume, that population decreases from about 82 million today to approx. 80 million in 2030. Whereas the demand for passenger transport will not change considerably until 2030, the demand for freight transportation increases more than 60% until 2030 compared to 2000. The real crude oil price is supposed to rise up to 135 $/bbl in 2030 (price basis 2010). According to the adapted Atomic Energy Act we assume the gradual phase out of nuclear power according Figure 2 [Federal Government of Germany, 2011a].

**Figure 2: Residual Capacity of Nuclear Power in Germany**

Table 2 gives an overview over the six different scenarios that we consider in this long abstract.

The Business as usual (BAU) scenario describes a path where Germany’s energy policy at the time before the “Energiewende” is considered and the further development takes place autonomously. The only exception is that GHG emission reduction goals are not considered. The BAU scenario therefore provides a basis for all other scenarios.
The scenario Energy Concept (EC) contains all the measures and goals defined in the updated Energy Concept of the Federal Government (an extraction can be found in Table 1) with one exemption. In this case the GHG reduction goal was excluded intentionally. In doing so, we examine the efficiency of the other goals in terms of helping to reduce the GHG emissions. It can also be detected, if there are any dual objectives that constrain the solution space unnecessarily.

The scenarios EC(CO2+CCS) and EC(CO2-CCS) are based on the EC scenario. In both variations the achievement of the governmental CO₂ reduction goal is ensured by an exogenous restriction. The only difference between these scenarios is the availability of the option to realize Carbon Capture and Storage (CCS) from 2020 on. The reason for this distinction is the controversial discussion about CCS, which already took place in Germany.

The scenarios OPT(CO2+CCS) and OPT(CO2-CCS) both are cost-efficient scenarios. The only restriction given in the model is the exogenous CO₂ reduction path according to the Energy Concept. For these calculations, all measures are optionally available and the model chooses the most cost-efficient measures/technologies portfolio to meet the CO₂ restriction. Once again we differentiate between having the option of CCS or not.

### Table 2: Calculated Scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BAU</td>
<td>Business as usual without CO₂ emission reduction goal and further measures</td>
</tr>
<tr>
<td>EC</td>
<td>Energy Concept of the German government with the exception of the CO₂ emission reduction goal</td>
</tr>
<tr>
<td>EC(CO2+CCS)</td>
<td>Energy Concept of the German government including CO₂ emission reduction goal with CCS option</td>
</tr>
<tr>
<td>EC(CO2-CCS)</td>
<td>Energy Concept of the German government including CO₂ emission reduction goal without CCS option</td>
</tr>
<tr>
<td>OPT(CO2+CCS)</td>
<td>Business as usual with CO₂ emissions reduction goal according to the Energy Concept with CCS option</td>
</tr>
<tr>
<td>OPT(CO2-CCS)</td>
<td>Business as usual with CO₂ emissions reduction goal according to the Energy Concept without CCS option</td>
</tr>
</tbody>
</table>

Source: Own compilation

### IV Business as Usual versus Energy Concept

This chapter discusses the computational results for the scenarios BAU and EC. First, the different effects on the total primary energy supply will be shown. Afterwards, the CO₂ emissions in both scenarios are being compared. After examining the
power station sector more in detail, the results for the final energy sectors will be discussed.

IV.1 Total Primary Energy Supply

Figure 3 shows the results for the total primary energy supply (TPES) for the BAU and the EC scenario. In both cases the exogenous forced phase out of nuclear power is observed. In the BAU scenario the TPES decreases by 15% until 2030 compared to 2010. This is due to autonomous improvements in energy efficiency and saving. This effect predominantly compensates the discontinuation of nuclear power. The share of renewables increases slightly, whereas the consumption of oil and gas declines a bit.

**Figure 3: Total Primary Energy Supply (left: BAU, right: EC)**

![Graph showing TPES for BAU and EC scenari]  
Source: Own compilation IEK-STE 2012

In the EC scenario the decrease of the TPES is more intense than in the BAU scenario. Besides of oil and gas also the consumption of hard coal and lignite is on the decline. As a result of the goals of the Energy Concept the renewables play a much stronger role as in the BAU scenario. The share of renewables in TPES amounts about 29% in 2030.

IV.2 CO₂ Emissions

The resulting CO₂ emissions for the BAU and the EC scenario are illustrated in Figure 4. Despite the phase out of nuclear power, even in the BAU scenario a reduction of CO₂ emissions is observed. This effect can be explained by autonomous im-
provements in energy efficiency and saving in the sectors residential, small consumers and industry. Even though the amount of freight transportation increases significantly, the CO₂ emissions in the transportation sector remain nearly constant for the BAU scenario. This is due to more fuel-efficient means of transport, which play an increasing role with rising fuel prices. In the BAU scenario a slight increase of CO₂ emissions takes place in the power station sector. The decline of nuclear power is mainly substituted by an enforced usage of fossil power plants, especially hard coal.

Although there is no explicit CO₂ restriction in the EC scenario, the emissions decrease by 51% until 2030 compared with the level of 1990. This is only slightly below the governmental objection for 2030 of 55% GHG emissions reduction compared to 1990.

**Figure 4: CO₂ Emissions (left: BAU, right: EC)**

Source: Own compilation

Despite the higher energy efficiencies and savings in the sectors residential and industry, the power station sector has a notable share in the decrease. For this reason the power sector will be discussed more detailed in the following.

**IV.3 Installed Net Capacity**

The installed net capacities for the scenarios BAU and EC are visualized in Figure 5. In the BAU scenario, the decline of nuclear power capacities is mainly compensated by new coal-fired power plants. The degree of expansion of renewables remains at a constant level after 2010. The total installed capacity after 2010 stays at a constant value of approximately 150 GW.
In the EC scenario the total installed capacity rises up to almost 200 GW in 2030. Besides the decline in nuclear power capacities, lignite as well as hard coal power plants are being decommissioned. In contrast the installed capacities of wind energy converters – on- and offshore – grow substantially. This growth is accompanied by the build-up of new gas turbines, which are particularly back-up capacities for the volatile electricity production from wind. Furthermore, an increase in “Others” – the biggest share is biomass – can be observed. Photovoltaics however, remain on the level of 2010. The reason for this effect is that the calculations are based on the absolute target of the share of renewables in electricity generation. A differentiation between different technologies of renewables was not made within the Energy Concept. This indicates that in our model calculations photovoltaics are not as cost-efficient as wind and biomass.

**Figure 5: Installed Net Capacity (left: BAU, right: EC)**

![Graph showing installed net capacity for BAU and EC scenarios.](image)

Source: Own compilation

IEK-STE 2012

### IV.4 Net Electricity Generation

Figure 6 illustrates the net electricity generation for both scenarios BAU and EC.

In the BAU scenario, the total power generation remains on a close to constant level until 2030. The decline of nuclear power is substituted by the increasing usage of - partly new - hard coal power plants.

In the EC scenario, the government’s objective of 10% less electricity consumption until 2020 becomes significant. By 2030, the decline amounts about 14% compared to 2010. The share of nuclear power decreases according to the phase out agree-
ment. Moreover, the power generation from lignite- and especially hard coal-fired power plants is put under pressure. In contrast the electricity production from wind turbines - on- and offshore - and from “Others” - mainly biomass - increases substantially. As described above, photovoltaics remain on the level of 2010 due to high costs. The electricity production from gas-fired power plants rises slightly. With regard to the installed capacities of gas-fired power plants, the actual operating time is extremely low.

**Figure 6: Net Electricity Generation (left: BAU, right: EC)**

![Diagram showing net electricity generation (left: BAU, right: EC)](image)

**Source:** Own compilation

**IEK-STE 2012**

### IV.5 Final Energy Demand

The final energy demand for the sectors transportation, residential, small consumers and industry is shown in Figure 7.

Induced by rising fuel prices, the final energy demand decreases in the BAU scenario by 10% until 2030 compared to 2010, meaning that technologies with higher energy efficiencies are used. In the EC scenario the decline is even stronger. The main sectors accountable for this development are residential, small consumers and industry.
In this chapter the cost-efficient scenarios OPT(CO2+CCS) and OPT(CO2-CCS) are compared with the scenario EC(CO2+CCS). The focus is on total primary energy supply, CO₂ emissions as well as net electricity generation.

V.1 Total Primary Energy Supply

The different primary energy supplies for the scenarios are illustrated in Figure 8. Compared to the scenario EC (Figure 3), the TPES reduction in scenario EC(CO2+CCS) is pronounced more strongly. The reason for this is that the additional CO₂ reduction requirement of about 4% (the difference between reached reduction and governmental objective in scenario EC) urges the use of further energy-saving technologies, which lowers the TPES.

In the cost-efficient scenario with CCS option the TPES is decreasing a little less compared to the Energy Concept scenarios. As one can see in the discussion on the electricity generation (Chapter V.3), the usage of CCS in electricity generation takes some pressure off energy saving needs.

If CCS is not an option, the TPES decreases even more than in the EC(CO2+CCS) scenario. This means that the model rather chooses more energy-saving technologies instead of e.g. expanding renewable energy sources.
For this reason the share of renewables in both cost-efficient scenarios is smaller than in the different Energy Concept scenarios.

Figure 8: Total Primary Energy Supply (left: EC(CO2+CCS), middle: OPT(CO2+CCS), right: OPT(CO2-CCS))

Source: Own compilation  
IEK-STE 2012

V.2 CO2 Emissions

The CO2 emissions for the three scenarios are shown in Figure 9. Since the governmental CO2 emission reduction goal is considered in all three scenarios, the overall emissions are similar, whereas the shares of the different sectors vary slightly. The biggest variation can be observed in scenario OPT(CO2+CCS), where the CO2 emissions in the power station sector are less than in the two other scenarios. The reason for this effect will be explained in the following chapter.

Figure 9: CO2 Emissions (left: EC(CO2+CCS), middle: OPT(CO2+CCS), right: OPT(CO2-CCS))

Source: Own compilation  
IEK-STE 2012
V.3 Net Electricity Generation

Figure 10 illustrates the net electricity generation for all three scenarios. Compared to the electricity generation in scenario EC (Figure 6), in scenario EC(CO2+CCS) CCS is used in lignite power plants for the first time in 2025. That means that the additional CO₂ reduction requirement of about 4% is mainly reached by using CCS. At the same time the electricity production from hard coal-fired power plants decreases slightly more than in the EC scenario.

In the OPT(CO2+CCS) scenario hard coal power plants are decommissioned after 2020, whereas gas-fired power plants play an increasing role. Lignite power plants get retrofitted with CCS technology, so that in 2030 most of the electricity production from lignite is coupled with CCS. Electricity production from wind turbines - on- and offshore - and from “Others” - mainly biomass - increases substantially. As seen before, the share of photovoltaics remains at the level of 2010, since the model chooses more cost-efficient technologies. Compared to EC(CO2+CCS) the total electricity generation decreases 4% less.

Since CCS is not available in the scenario OPT(CO2-CCS), the technology cannot be realised. While most of the hard coal power plants are decommissioned until 2020, the amount of electricity generation from lignite power plants without CCS technology remains almost stable. In 2030 the electricity is imported for the first time. As an import option for electricity we assume a relative expensive source for electricity, comparable to the Desertec project in the north of Africa. The overall electricity generation decreases to the same level as in the EC(CO2+CCS) scenario.

Figure 10: Net Electricity Generation (left: EC(CO2+CCS), middle: OPT(CO2+CCS), right: OPT(CO2-CCS))

Source: Own compilation IEK-STE 2012
VI Cost Analysis

This chapter discusses the economic impacts of the diverse technology/ measures portfolio within the scenarios. The basis of comparison for the Energy Concept (red) and cost-efficient (green) scenarios is the BAU scenario. The additional annual costs of the discussed scenarios as compared to BAU are illustrated in Figure 7.

**Figure 11: Additional Annual Costs as Compared to BAU**

The additional annual costs of the EC scenario are increasing up to 29.4 billion € per year in 2030. This is approximately 0.9% of the annual GDP in 2030. In the time period from 2010 to 2030 the cumulative additional costs add up to 265 billion € (not discounted).

Both Energy Concept scenarios that meet the CO₂ restriction (OPT(CO₂+CCS), OPT(CO₂-CCS)) bare increasing costs compared to EC after 2020. The Energy Concept scenario without the option of CCS has the highest system costs.

The additional annual costs of the OPT(CO₂+CCS) scenario are increasing up to 13.4 billion € per year in 2030, which is about 0.4% of the annual GDP. The additional annual system costs are therefore almost half of the costs in the EC scenario for the whole period.

If CCS is not an option, the additional annual system costs rise rapidly after 2020. In the year 2030 the costs reach nearly exactly the level of the costs in the EC scenario.
Nevertheless the different dynamics lead to lower cumulative additional system costs for the period from 2010 to 2030 in the amount of 220 billion €.

VII Outlook

In this long abstract we showed our first results of recent scenario analysis concerning the German Energy Concept. In the full paper we will describe all results in detail and we will also present further indicators such as specific space heat demand, specific fuel consumption and CO$_2$ emissions by cars, energy demand per industrial gross value added or marginal CO$_2$ reduction costs.

VIII References


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01/2012 Schlör, H., Fischer, W., Hake, J.-F.: Measuring social welfare, energy and inequality in Germany.


03/2012 Kronenberg, T.: Nachhaltige Stabilisierungspolitik.

Many of the issues at the centre of public attention can only be dealt with by an interdisciplinary energy systems analysis. Technical, economic and ecological subsystems which interact with each other often have to be investigated simultaneously. The group Systems Analysis and Technology Evaluation (STE) takes up this challenge focusing on the long-term supply- and demand-side characteristics of energy systems. It follows, in particular, the idea of a holistic, interdisciplinary approach taking an inter-linkage of technical systems with economics, environment and society into account and thus looking at the security of supply, economic efficiency and environmental protection. This triple strategy is oriented here to societal/political guiding principles such as sustainable development. In these fields, STE analyses the consequences of technical developments and provides scientific aids to decision making for politics and industry. This work is based on the further methodological development of systems analysis tools and their application as well as cooperation between scientists from different institutions.

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