Institute of Energy Economics at the University of Cologne
Exploring energy markets – enhancing decisions.

Summary June 2013

Study of electricity trends 2022

Stress test for the Energiewende

www.ewi.uni-koeln.de

Content

The following summarises the study "Study of electricity trends 2022 – Stress test for the Energiewende" commissioned by BDI – Bundesverband der Deutschen Industrie e. V. (Federation of German Industries).

Authors

EWI
Joachim Bertsch
Prof. Dr. Marc Bettzüge
PD Dr. Christian Growitsch
Harald Hecking
Stefan Lorenczik

ie^3 and ef.Ruhr
Volker Liebenau
Prof. Dr. Christian Rehtanz
Johannes Schwippe
André Seack

Published
June 2013

Herausgeber
Institute of Energy Economics at the University of Cologne (EWI)
Alte Wagenfabrik, Vogelsanger Str. 321, 50827 Köln, Germany

Photos
Title: Photo 1 und 4: Fotolia, Photo 3: iStockphoto,
Photo 2: Gerhard Launer WFL-GmbH, Schiesshausstr. 14,
97228 Rottendorf, Germany, Tel.: +49 (0)9302 9081-0,
Fax: +49 (0)9302 9081-41

Design
Gute Botschafter GmbH, Köln, Germany

The Institute for Energy Economics at the University of Cologne (EWI) is an independent research institution that is affiliated to the university and sponsored by a Society of Benefactors. The Institute is currently being chaired by two professors from the Faculty of Economics and Social Sciences at the University of Cologne, together with two associate professor designates. Based on an outline agreement governing the period from 2009 to 2013 between the University of Cologne, the Society of Benefactors, the state of North-Rhine Westphalia, and E.ON and RWE, EWI receives material and financial support from all five parties to the agreement. Additional support is covered by third-party funding.The institute's management board is responsible for the allocation of funds.

1 Background, research objective and methodology

When it published the Energy Concept in September 2010, the Federal Government presented an ambitious scheme for redesigning the German energy system. The Concept defines guidelines for German energy policy up to 2050, and was later enhanced by the Energy Package in June 2011 (in the wake of Fukushima). One of the energy policy goals between now and 2020 is to reduce greenhouse gas emissions in Germany by 40% (compared to 1990). Furthermore, the Concept envisages that renewable energies will account for an increased share of at least 35% of gross electricity consumption, and that net electricity consumption will decline by 10% (compared to 2008). A gradual phase-out of nuclear energy between now and 2022 was also agreed upon. The term "Energiewende" was coined to denote the shift in energy supply from primarily fossil fuels and nuclear power to renewable energies and sources with enhanced energy efficiency.

For the first time, this study has subjected the Energiewende to a comprehensive stress test. It examines key influencing variables of the Energiewende with respect to their impact on the energy policy goals of cost efficiency and supply reliability. Influencing variables include the extension of the transmission systems, increased energy efficiency (defined as reduced demand for electricity), the construction of new power plants (especially in southern Germany), the expansion of renewable energies, and price trends for fuels and CO_2. These are varied within a certain range of possible developments, whereby the effects of different deviations from the predefined targets are highlighted. The study is based on a quantitative, model-based multi-scenario analysis of the electricity system, taking into account the load flows of the transmission system. Extreme situations, in which the supply system is exposed to particular stress, have been simulated as part of the analysis procedure. The study focuses on the development of the electricity sector over the next ten years, – with the period under review beginning in 2012. Statements relating to the overall effects of the Energiewende cannot be made since the study only deals with developments from the year 2012 onwards. Any interpretation of the results must bear in mind that 2022 only marks an interim milestone, and not the end of the transformation process.

In the "political target scenario", which serves as the reference case, the energy policy goals with respect to electricity generation and transmission systems are assumed to be met in full. The political target scenario serves as the basis for analysing the various deviations and should be interpreted accordingly in this context. Alternative scenarios are used to examine the outcome resulting from deviating the individual sub-targets or measures from the reference case. The study does not analyse the probability of possible developments occurring, but rather aims to quantify the consequences of deviating from the reference cases.

In doing so, the period between the reference years 2012 and 2022 is examined in two-year increments – an approach that permits both spot analysis and representation of the dynamic effects of fundamental influencing factors. The relevance of the various influencing variables and their interdependencies, the consequences of deviating from the planned development path, allow for stress testing of the Energiewende.

The results in this study represent simulated scenarios and do not constitute forecasts. Scenarios analyse various possible developments, and any interpretation of the results must always bear the underlying assumptions in mind. Since all scenarios are based on the same underlying assumptions, any comparison allows the effects of individual influencing factors to be isolated. As such, the identified effects are not directly influenced by the underlying assumptions, although the assumptions can produce variations in the extent of the effect.

2 The Political Target Scenario

The "political target scenario" describes the development of the electricity system based on the central assumptions of the publicly reviewed lead scenario (Scenario B) for the Network Development Plan 2012.[1] Installed capacities of renewable energies are assumed to be 54 GW photovoltaic, 47.5 GW onshore wind and 13 GW offshore wind by 2022. Prices are assumed to be 26 €/MWh_{th} for natural gas, 9.7 €/MWh_{th} for hard coal and 24.5 €/MWh_{th} for CO_2. Deviations from the lead scenario are assumed, such that the political goal of reducing demand is realised. In the following, this political target scenario serves as the reference case for the analysis of the influencing factors in order to ensure the comparability of the individual scenarios.

In the political target scenario, renewable energies would account for an increasing share of gross electricity consumption, namely 48% in 2020 and 54% in 2022. During the period considered, Germany would be a net electricity exporter, generating surplus power of more than 70 TWh in 2018 and more than 50 TWh even once nuclear energy has been completely phased out. Following a brief increase in the power generated from lignite and hard coal, the reduction in demand and expansion of renewable energies would cause coal-based power generation to decline over the long term. In light of the assumptions regarding fuel and CO_2 prices, however, coal would retain its dominance among fossil energy sources (Figure 1).

In this case, CO_2 emissions in the German electricity sector would drop to around 221 million t in 2020, equating to a reduction of 38% (compared to 1990). As the process of phasing out nuclear energy would be partly offset by fossil fuel production, CO_2 emissions between 2020 and 2022 would remain constant.

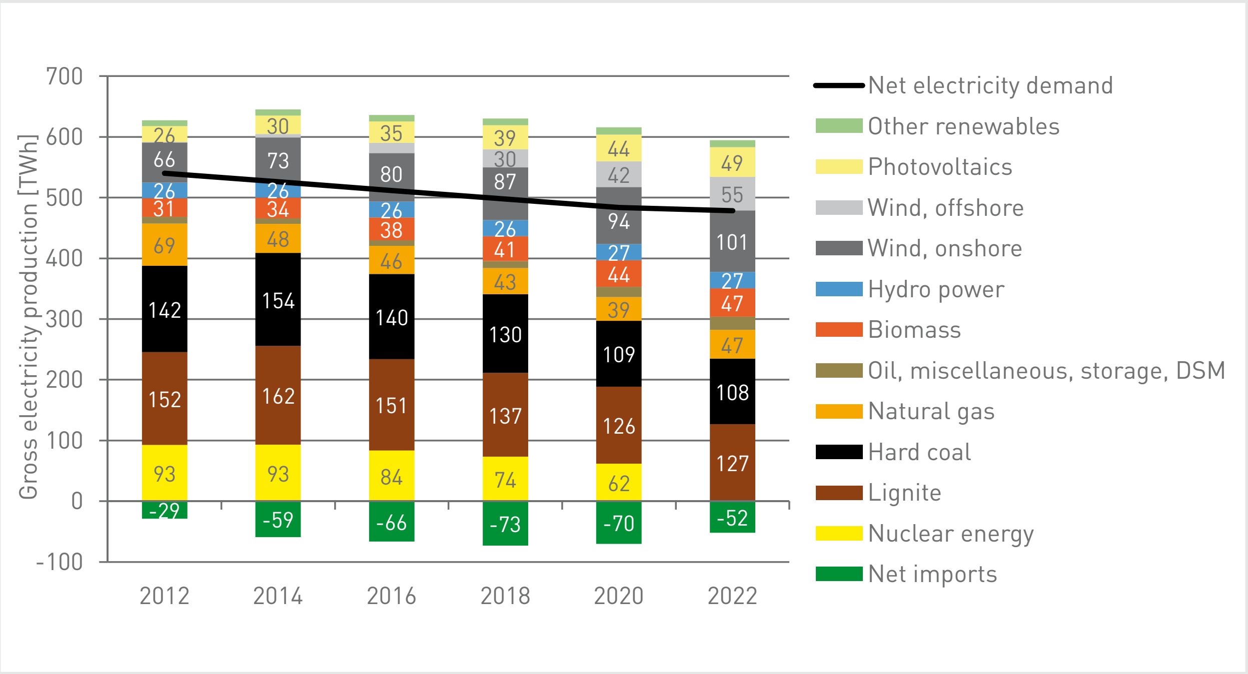

Figure 1: Gross electricity production in the political target scenario

---

[1] In Scenario B, Network Development Plan 2012, the following fuel prices are assumed for 2022: 26 €/MWh_{th} for natural gas, 560 €/t for crude oil, 79 €/t coal equivalent for hard coal. The price of CO_2 was assumed to be 26 €/MWh_{th} in the Plan. This study is based on the average EEX price for the first six months of 2012 and on the appropriate futures price for 2014. Linear interpolation was performed for the other interim years using the mean values for 2032 in the Network Development Plan 2012 and the energy scenarios published by the Federal Government in 2011.

The annual costs[2] of the electricity system would rise from 47.7 billion Euros in 2012 to 62.4 billion Euros in 2022, largely due to the higher costs resulting from an increase in electricity produced from renewable energies. For 2012, annual costs would be 50.6 billion Euros when taking into account the annualised capital costs associated with nuclear power stations (Figure 2). Prices per kilowatt hour would rise by approximately 4 ct/kWh, as the reduction in demand would mean spreading the increased costs over fewer kilowatt hours.

Assuming the expansion of conventional capacities and implementation of the planned network development measures, supply reliability would be guaranteed at all times. An increased need for reactive power, i.e., energy not available for end use but needed to sustain system stability, would arise in situations of high demand and high wind feed-in, especially in the Ruhr district.

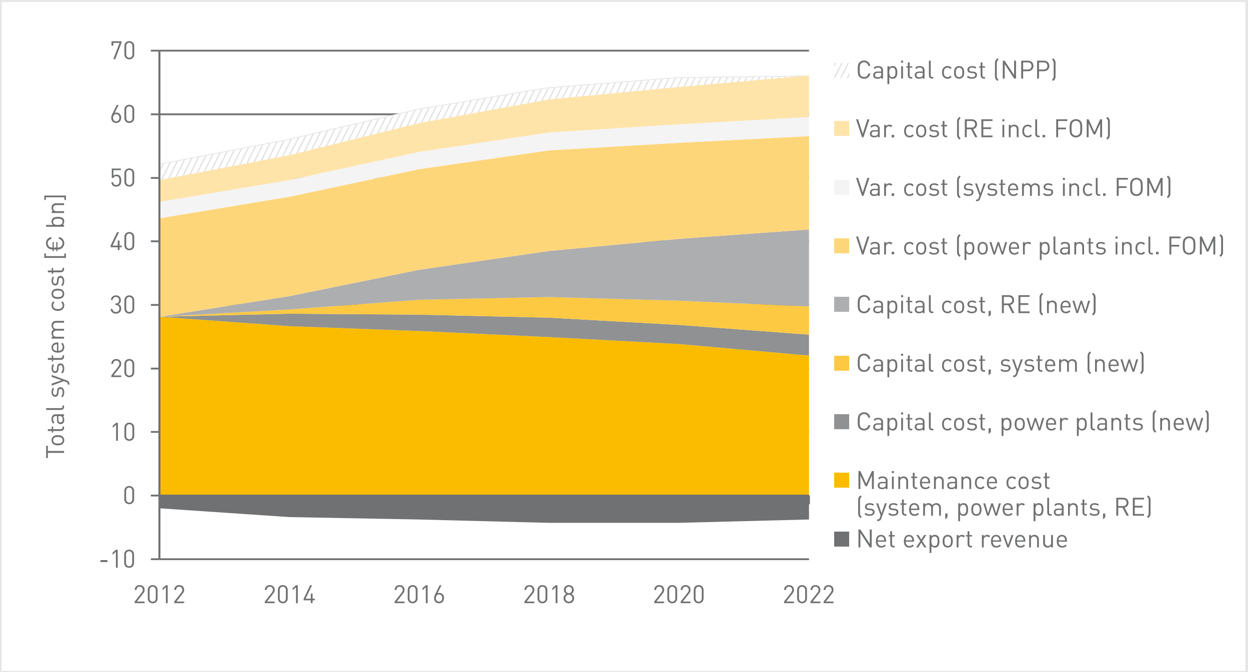

Figure 2: Total system cost in political target scenario[3]

---

[2] The costs indicated in the results represent the cost of running the electricity system. Conclusions cannot be drawn directly with respect to prices and remuneration.

[3] FOM are fixed operating and maintenance costs and include, for example, insurance and personnel costs.

3 Key findings from the stress test

The study uses multiple variations of influencing factors to perform a stress test on the development of the electricity system between 2012 and 2022, highlighting the relevant effects of these influencing variables. Based on the political target scenario, the analysis pinpoints the influencing variables that could potentially jeopardise the realisation of the Energiewende. Five key influencing variables are studied: grid expansion, the generation system, renewable energies (RE), demand, and CO_2 and fuel prices. The approach should be interpreted as a positive rather than normative analysis.

Influencing Variable: Grid Expansion

The implementation of all of the measures in the Network Development Plan (NDP) would allow RE generation plants to be almost completely integrated. Without NDP measures, systematic RE curtailment would occur from 2016 onwards in the initial grid[4]. As time progresses and the expansion of RE capacities continues, curtailment would become more frequent and would ultimately reach nearly 8 TWh in 2022 (Figure 3). This amount would be counterbalanced by conventional generation. As such, renewable energies would only account for about 46% of electricity generation in the initial grid in 2020, and about 52% in 2022.

If only the initial grid was implemented, the concentration of power generation in the north and lack of generation in the south would produce a higher risk of not being able to meet demand in the south during strong wind conditions from 2018 onwards. In 2022, this would affect about 1% of the load in the initial grid in extreme situations. Inner-German redispatch measures would then no longer be sufficient to ensure load coverage. Possible solutions could be to shed loads, overload the grid or intervene in European trade. The situation would also be tense if the extra high voltage direct current transmission lines (EHVDC lines) in the electricity grid were not expanded.

Extreme situations with strong winds occurring between now and the assumed implementation of the NDP expansion measures in 2016 could also produce critical situations and jeopardise load coverage. Such situations would occur primarily in the early hours of the morning when loads are relatively low. Here, again, inner-German redispatch measures would be unable to compensate the shortfall, and additional actions would need to be taken.

Failure to implement the actions defined in the Network Development Plan would also directly affect the goal of using renewable energies to reduce CO_2. The ratio of cost to CO_2 reduction in the initial grid would be less favourable if the trajectory were higher, i.e., it would cost more to achieve the same level of CO_2 reduction. A trajectory of 4 GW p.a. would only produce a reduction of about ~14 million t CO_2 in the initial grid, compared to ~22 million t with the NDP expansions (Figure 4).

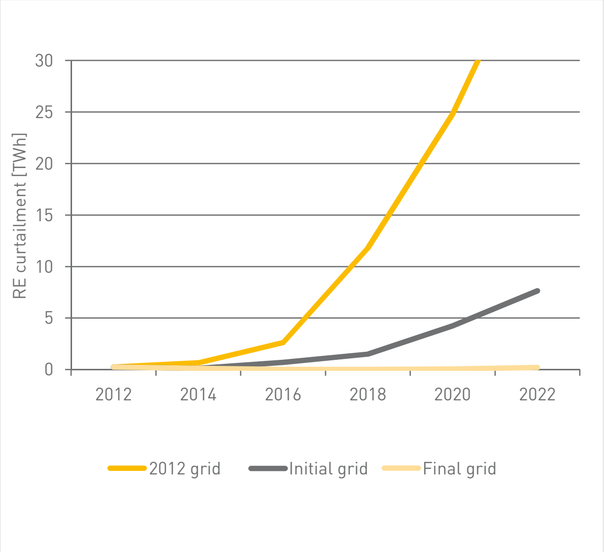

Figure 3: RE curtailment trends for different grid expansion variations

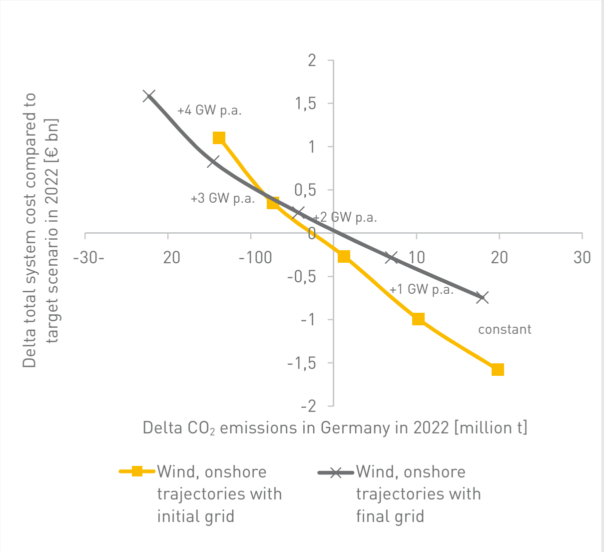

Figure 4: Delta total system costs and CO_2 emissions of onshore trajectories compared to the target scenario in 2022

---

[4] Implementation of all EnLAG measures, projects that already have planning approval, measures in an advanced state of planning, taking account of current delays.

Given the proposed plans to drastically change the electricity supply system, the current institutional framework could jeopardise supply reliability. At present, the trading of electricity between – mostly national – market regions presumably prevents shortages occurring in a market region. However, in extreme situations, efforts to generate trading income could cause shortages in a market region. For example, strong winds in northern Europe may result in massive exports to Germany; however, at the same time, the wind feed-in keeps prices down in Germany, resulting in exports to southern neighbouring countries. These trade-driven north-south transits burden the inner-German transmission system and jeopardise supply reliability.

Influencing variable: Generation system

Failing to build additional new capacities would result in an inability to cover the peak load (as recorded in 2010) with German capacities from 2022 onwards (Figure 5). Failure to replace disconnected power plants or dismantle older power plants would further increase the risk of shortfall. In average situations with normal loads, the options of feeding in renewables and importing energy ensure that critical situations would not arise. If, however, renewables were not available (i.e., during phases of weak winds), and supply from abroad was not an option, shortages would occur and supply reliability would be at risk. Concentrated generation capacities in the north with simultaneous low production capacities in the south would not impact supply reliability if the Network Development Plan was to be implemented. The expansions envisaged in the NDP would assure proper transmission from the place of generation to the load centres.

Influencing variable: Renewable energies

Further expanding wind and photovoltaic energy would cause annual CO_2 emissions in Germany to decline by a total of about 47 million t CO_2 in the target scenario between now and 2022 (Figure 6). Photovoltaics would only contribute about 18% to this CO_2 emission reduction, but would account for about 42% of the necessary investment costs (Figure 6). The resulting cost of reducing CO_2 in Germany using photovoltaic energy would be ~404 €/t, which is about three times more than that of offshore wind and eight times more than that of onshore wind.

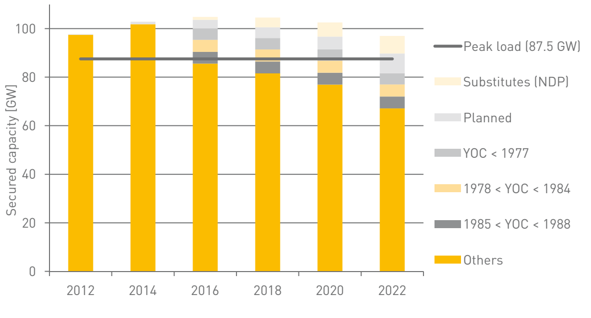

Figure 5: Development of secured capacity[5]

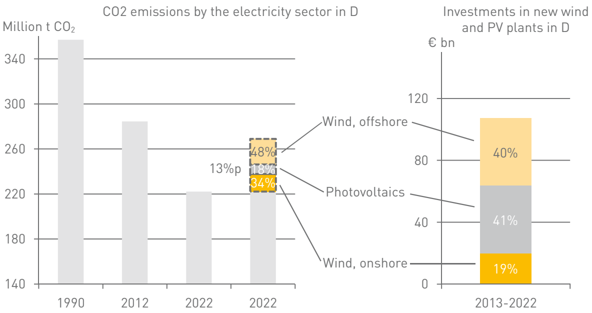

Figure 6: Contribution towards CO_2 reduction in 2022 and investment costs between now and 2022

---

[5] YOC = Year of commissioning.

Based on the assumptions of the target scenario, failure to expand electricity generation from renewable energies would push the total system cost in 2022 up to 54.4 billion Euros (Figure 7). Including investments in grid expansion, renewables would cause an inrease in costs of 7.9 billion Euros (14.6 %).

In total, the electricity system would cost 556 billion Euros over the period from 2013 to 2022. If no further wind and PV capacities were built (compared to the current status), the cost would total 511 billion Euros. Without these additional capacities, the other costs, i.e., fuel and CO_2 costs, would increase by about 13 billion Euros. At the same time, adding new RE capacity would avoid costs of about 58 billion Euros (Figure 8). Thus the additional costs of the Energiewende amount to 45 billion Euros.

The cost of reducing CO_2 emissions in Germany would increase if more wind energy was added than planned in the target scenario, since not all of the electricity can be transmitted to the load centres. In the case of photovoltaic energy, by contrast, the cost would remain relatively constant if the distribution systems were to be disregarded. Yet, due to lower investment costs and higher full load hours, onshore wind would still be a cheaper alternative than photovoltaic given a huge expansion of renewable capacities.

Any excess capacity above 4 GW p.a. of additional onshore wind energy could not be fully integrated into the electricity system. In light of the expanded capacity, the system cost would increase but would no longer be able to fully account for CO_2 abatement: As capacity expanded, wind energy would be curtailed due to either market or grid constraints (Figure 9). Photovoltaic energy would not show such effects in the transmission grid, since the timing of load and generation is better matched. Certainly, the impacts on the distribution systems would need to be taken into consideration.

More than one-third of the RE capacity that is additionally generated would only serve to increase the German export surplus. Between 2012 and 2022, the Network Development Plan envisages an increase of 35 TWh in onshore wind, 54 TWh in offshore wind and 23 TWh in photovoltaic energy (Figure 10). Only two-thirds of this amount of electricity would displace domestic conventional power generation and thus prevent CO_2 emissions in Germany. The other one-third of the additional power generated from renewable energy sources would eliminate the need for conventional production abroad and would therefore improve the CO_2 balance of other countries.

Influencing variable: Demand

The efficiency target denoted by the demand for electricity is a key lever for future CO_2 reduction. If electricity demand was to remain stable and thus misses the target of a 10% reduction, this would result in an additional 24 million t of CO_2 emissions in 2022 (Figure 11) in the German electricity sector (compared to the target scenario). As a general rule, for each TWh not consumed in the 2022 electricity system, CO_2 emissions in Germany are reduced by 0.3–0.4 million t.

If electricity demand was to remain constant, the annual total cost of the electricity system in 2022 would be about 65.2 billion Euros, which would be about 2.8 billion Euros more than envisaged in the target scenario. The cost per kilowatt hour of electricity would, however, be lower since the costs would be spread over a greater number of demand units. Accordingly, the cost per kilowatt hour would be about 0.9 ct/kWh less than the target scenario.

Constant levels of demand would not impair supply reliability. At neither a constant level of demand nor an increase in demand of 1.0% per year would we see significant amounts of RE generation being curtailed or potential gaps in supply.

Influencing variable: Price of gas and CO_2

The relative price of different conventional primary energy sources is an important driver of the environmental compatibility of electricity generation. If natural gas were to cost 18 €/MWh_{th}, hard coal 10 €/MWh and CO_2 24.5 €/t, a fuel switch from hard coal to natural gas would occur. Modern gas-fired power stations would then replace older, less efficient coal-based power plants (Figure 12). The same would apply to gas-fired power stations in the Netherlands, some of which could produce electricity at lower costs than certain coal-based power plants in Germany.

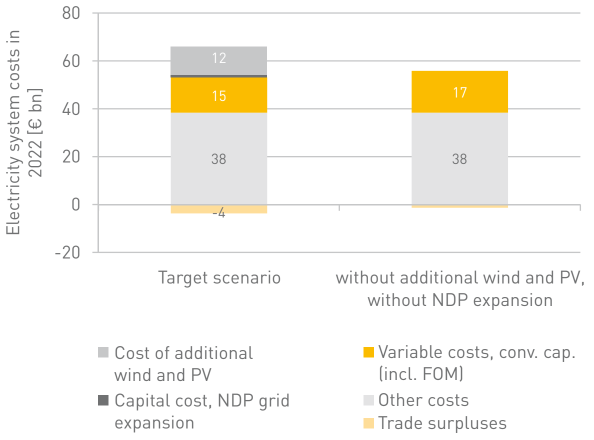

Figure 7: Total system cost in 2022 with and without RE expansion

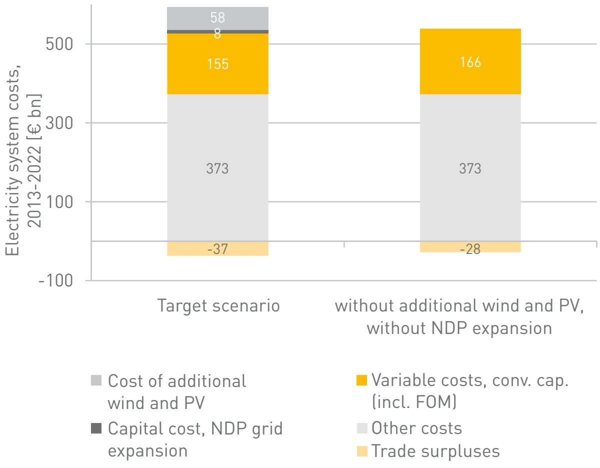

Figure 8: Cumulative total system cost 2013–2022 with and without RE expansion

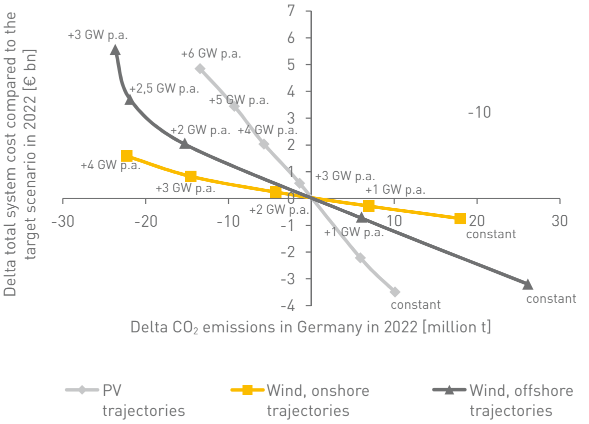

Figure 9: Delta total system cost and CO_2 emissions in 2022 compared to the target scenario in 2022

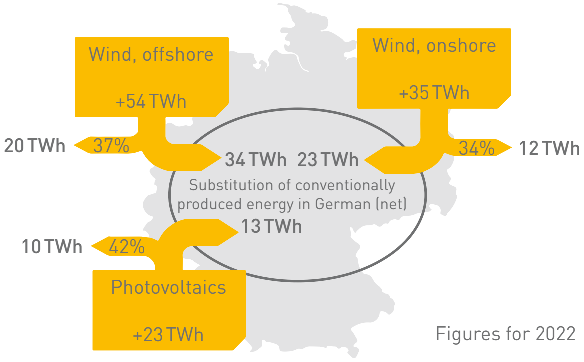

Figure 10: Impacts of additional RE capacities on the net trade balance

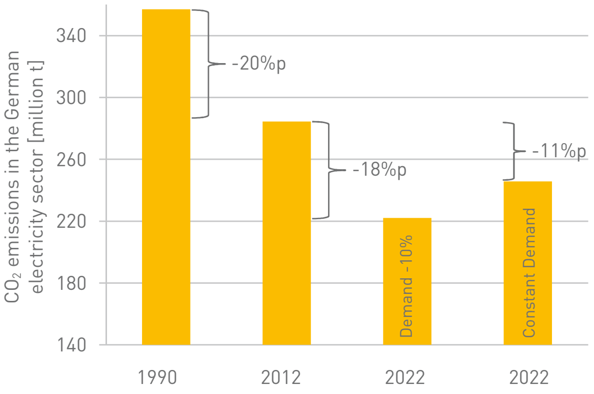

Figure 11: CO_2 emissions trend in the German electricity sector

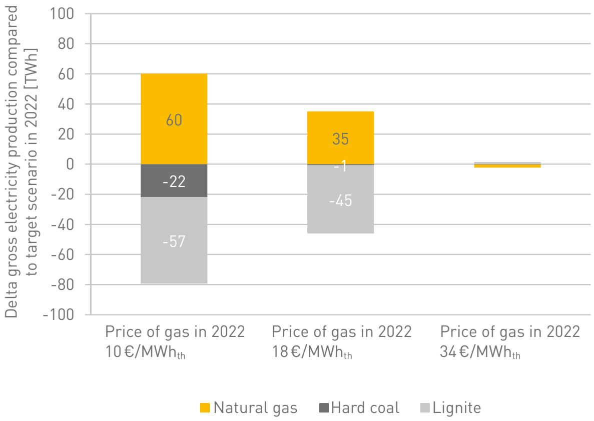

Figure 12: Delta production volumes in German power plants in 2022 at different gas prices compared to the target scenario

Equally, a CO_2 price of 40 €/t in 2022 would prompt a switch from coal to natural gas[6] (Figure 13). A high gas price would require a higher CO_2 price to prompt a fuel switch. A wider difference in the price of both energy sources would therefore make it more expensive to avoid CO_2 by generating electricity from natural gas.

Switching fuel at a gas price of 18 €/MWh_{th} in 2022 would produce a CO_2 reduction of 44% (compared to 1990) and would thus increase CO_2 reduction by 6 percentage points. A fuel switch prompted by the lower gas price would reduce CO_2 by 21 million t in 2022 (compared to the target scenario). By contrast, assuming the price of gas is higher than the target scenario (34 €/MWh_{th} in 2022 instead 36 €/MWh_{th}), a fuel switch would not occur and CO_2 emissions would ultimately remain unchanged (Figure 14).

As can be seen, a variation in the CO_2 price would directly impact on system costs. A difference of 10 €/t CO_2 would alter the annual total system costs by 1.8–2 billion Euros in 2022. A higher CO_2 price would push up the variable costs of the fossil-based power plants, which will still be producing nearly 50% of Germany's gross power in 2022. Since the CO_2 emission certificate prices constitute ETS income, however, funds are essentially redistributed. As such, higher emission prices only produce actual additional costs to a limited extent.

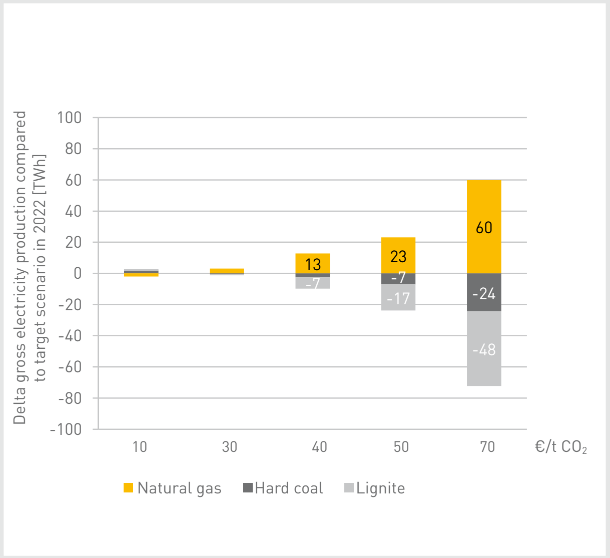

Figure 13: Delta production volumes in 2022 at different CO_2 prices compared to the target scenario

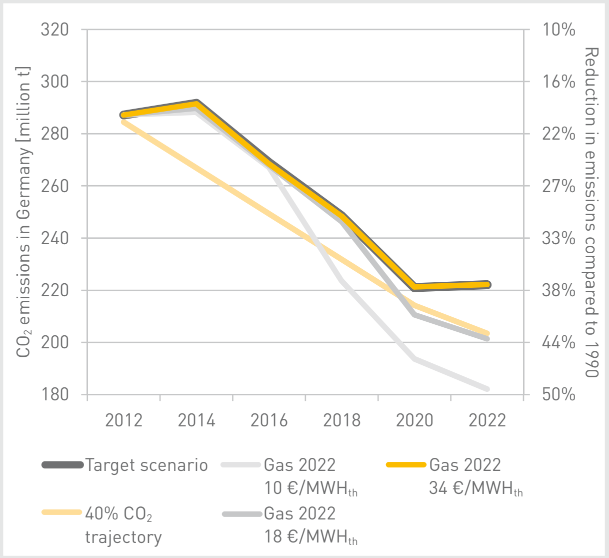

Figure 14: The effect of different gas prices on CO_2 emissions in the German electricity sector

---

[6] Assuming gas costs 26 €/MWh_{th} and hard coal about 10 €/MWh_{th}.

4 Recommended actions

The following recommended actions are derived from a collaborative assessment by the German Energy Agency (Deutsche Energie-Agentur GmbH, dena) and the Institute of Energy Economics at the University of Cologne (EWI).

A system approach and regulatory policy need to be considered to a greater extent.

Political discussions about changes to the energy system tend to address individual technologies, such as renewable energies, electricity grids or storage systems separately from each other. Looking ahead, focus should centre on the energy system as a whole. Lack of coordination in expanding renewable capacities, for example, will lead to an increased switch off of renewable energy plants and thus higher costs if the grid is not expanded in time. Measures to reshape the electricity supply system should, therefore, take all interdependencies into consideration. Such interdependencies and system effects become transparent and are reflected in market prices in the EU common market. An optimised system uses these market signals to its advantage and thus becomes more efficient in achieving its targets. Unlike numerous individual targets, focusing on a few system-relevant targets (such as reducing CO_2 emissions) permits greater flexibility in achieving targets, and therefore ultimately promotes greater market involvement and efficiency.

Grid expansion needs to be accelerated and better coordinated with RE expansion.

Phasing out nuclear energy and expanding renewable energies in locations that are distant from the load centres will necessitate considerable additional power lines. If grid expansion lags behind the trajectories of the electricity Network Development Plan 2012 in the future, renewable energies will have to be curtailed. This will push up costs and increase German CO_2 emissions. The development as well as the market and system integration of renewable energies therefore require rapid and extensive expansion of the electricity grids. By the same token, the expansion of renewable energies should be synchronised with the grid expansion. Measures implemented so far to speed up the grid expansion should be rigorously continued, and additional steps should be taken.

German energy policy must be embedded in the European framework.

The individual EU Member States are still each pursuing their own national energy policies with little or no coordination. The expansion of renewable energies is a prime example of the problems caused by a lack of coordination. Making use of different levels of wind incidence and sunshine, differing consumption patterns and storage potentials at a European level would produce considerable improvements in efficiency. For example, expanding renewable energies in Germany will not reduce CO_2 in Europe because of common emission trading. These trading activities do, however, reduce the price of electricity and CO_2 in Germany and throughout Europe, prompting appropriate adjustments by our neighbours. The pan-European coordination and implementation of German measures in the electricity sector would eliminate the inefficiencies caused by countries acting on their own. Regional cooperation (e.g., within the region of central and western Europe, CWE) could be a practicable interim step.

The electricity market needs redesigning.

Based on the EEG, renewable energies have been expanded to a great extent and at considerable speed in Germany's electricity sector. The EEG has, however, resulted in inefficient promotion of RE, making the achievement of both RE and CO_2 targets more expensive than necessary. It is essential that renewable energies are extensively integrated into the electricity market in order to ensure their efficient expansion and the creation of an efficient overall energy system. The Energiewende is drastically changing the requirements for electricity market design. Renewable energies incur investment and overhead costs, above all, and only minor variable costs. The current market design is inadequately equipped to cope with this characteristic. Growing shares of renewable energies, coupled with the reduced operating hours of conventional power plants, mean that the latter's future (cost-efficient) operation is surrounded by huge uncertainties. In addition, failure to expand the grid is causing capacity risks, especially at the regional level, e.g., in southern Germany. The design of the electricity market needs to be overhauled to meet the changing requirements. In doing so, the market integration of renewable energies must form the core of the new market design, as must the assurance of a high level of supply quality and further progress towards a (complete) common European energy market. Until then, a revision of the EEG needs to introduce control elements of a market economy in order to encourage more cost-efficient expansion, i.e., efficient technologies and efficient locations, in the short term.

We need to push ahead with improving energy efficiency.

Tapping energy efficiency potential reduces CO_2 emissions and makes sense from both an overall economic and business management perspective if the associated measures are profitable. Measures to improve energy efficiency generally involve investment (by private households, companies or the public sector). Such investment decisions should always weigh up the cost and benefit for consumers. Policy makers should, however, support investments when the market fails to do so. This means, for example, providing information through energy advice, defining standards, or by offering financial incentives. If the market fails, the Federal Government must set up long-term and consistent funding mechanisms and adopt a more pro-active approach towards information and motivation campaigns focusing on energy demand.

www.ewi.uni-koeln.de

Energiewirtschaftliches Institut
an der Universität zu Köln

Institute of Energy Economics
at the University of Cologne

Alte Wagenfabrik
Vogelsanger Str. 321
50827 Cologne / Germany

Tel.: +49 (0)221 277 29-100
Fax: +49 (0)221 277 29-400