Germany's nuclear phase-out: Impacts on electricity prices, CO_2 emissions and on Europe

Brigitte Knopf[1,a], Michael Pahle[a], Hendrik Kondziella[b], Fabian Joas[a], Ottmar Edenhofer[a], Thomas Bruckner[b]

[a]Potsdam Institute for Climate Impact Research (PIK), PO Box 60 12 03, 14412 Potsdam, Germany

[b]Institute for Infrastructure and Resources Management (IIRM) at the University Leipzig, Grimmaische Straße 12, 04109 Leipzig, Germany

Abstract

Following the nuclear meltdown in Fukushima Daiichi, the German parliament decided in summer 2011 to phase-out nuclear power by 2022. We investigate which influence this decision has on national and European electricity prices and on CO_2 emissions and to which extent this decision is influencing European energy policy. A model-based analysis of electricity prices and CO_2 emissions let us conclude that emissions can be kept at levels that are in line with the national reduction targets. Electricity prices for consumers will hardly be affected by the decision on the phase-out, whereas those for industry will increase due to the phase-out. A comparison with results from other studies shows that some model assumptions, e.g. the gas price, have a much larger influence on the electricity price than the nuclear phase-out itself. An empirical analysis reveals that the effect on the electricity prices for other European countries was only short-term but that a long-term influence of the German nuclear phase-out on the prices cannot be determined yet. We argue that for avoiding an excessive increase in costs the transformation of the German energy system requires further European coordination beyond the current level.

Keywords: Nuclear phase-out, electricity price, Germany's energy transition

[1] Corresponding author: Brigitte Knopf, Potsdam Institute for Climate Impact Research (PIK), PO Box 60 12 03, 14412 Potsdam, Germany, knopf@pik-potsdam.de, Tel.: +49 331 288 2631, Fax: +49 331 288 2570

1 Introduction

Following the nuclear reactor accident in Fukushima Daiichi, the German parliament decided in summer 2011 to phase-out nuclear power by 2022. This involved a strong discussion in the public (e.g. Ethics Commission 2011) and the decision also raised a lot of interest on the international level (e.g. van Noorden 2011). But the phase-out in 2011 was not the first decision to withdraw from nuclear power. In 2002, the former government already agreed to phase-out nuclear with the "nuclear consensus" between the federal government and the industry. Based on an average operational life-time of 32 years for a nuclear power plant, a phase-out was agreed upon with the last nuclear power plant to go off the grid by around 2023. However, in 2010, the new conservative government decided to go for a life-time extension of nuclear power up to 2038 as a "bridging technology" in order to facilitate the "road into the age of renewable energies" (Federal Government 2010) what is called the energy transition (Energiewende). In that sense, the second decision on the phase-out in 2011 constituted (again) a strategic reversal. Without discussing the details of this decision and the potential political reasons for the life-time extension, this leaves the question not only on the influence of the phase-out on prices and emissions but also if the now earlier phase-out – or even earlier phase-outs discussed back then – imply serious challenges for the overall energy transition compared to the previously mandated prolongation. In this paper, we analyse different pathways for the nuclear phase-out and narrow our scope by looking at its impacts regarding the originally envisaged role, i.e. to curb the increase of electricity prices for industry and consumers and to decrease CO_2 emissions.

The first part of the analysis looks back at the time before the nuclear prolongation was revoked and allows us to evaluate the different policy options that were discussed then. Besides the precise date of exit from nuclear energy, an important and long-term political discussion concerns the possible replacement options of nuclear power. We identify the required replacement capacities and use a power market model to analyse the differences in prices and emissions between early (2015 and 2020), the currently decreed (2022) and the previously planned (2038) phase-out. In that context, a range of different replacement options (for example, giving priority to coal or gas-fired power plants) is evaluated. As model results depend heavily on input assumptions, these paths are tested for their robustness in sensitivity analyses in which individual assumptions are varied. In this way, a range of alternative scenarios is explored. In order, for example, to evaluate the importance of energy efficiency measures, the influence of (electricity) demand-side management and the failure of efficiency measures are analysed. In addition, different expansion paths with regard to decentralised cogeneration as well as more steeply rising fuel and CO_2 prices are considered. This sensitivity analysis is completed by a comparison with electricity prices from other studies that evaluate the difference between a phase-out in 2022 and a life-time extension until 2038. A number of studies from different institutions were commissioned to evaluate the effect of a phase-out on electricity prices (enervis energy advisors (2011), Prognos/EWI/GWS (2011), IER/RWI/ZEW (2010), r2b energy consulting/EEFA (2010) and PIK/IIRM by Knopf et al. (2011a)). The comparison of these studies allows us to assess the range of results for the situation-as-is and their potential underlying causes and to distil robust messages for policy-makers over the whole portfolio of available scenarios.

Although Germany's decision on the nuclear phase-out was taken unilaterally, it does not only have an effect on German electricity prices and CO_2 emissions but has also an effect on the European scale. Two effects have to be analysed in this context are: First, the effect on electricity prices in neighbouring states and second, the effect on the CO_2 price. Therefore, we leave the purely national perspective and indicate some consequences of the German nuclear phase-out on other European countries. This is based on an empirical analysis of the influence of the phase-out on electricity baseload future prices for France and on the prices for CO_2 certificates in the European emissions trading scheme (EU ETS).

Finally, we adopt the broader perspective of the German energy transition beyond the nuclear phase-out that mainly means a transition towards an energy system with a major share of renewable energies. We investigate the interplay with Europe and show that for avoiding an excessive increase in costs the transformation of the German energy system requires further European coordination beyond the current level.

It should be noted in advance that we concentrate here solely on the effect of the nuclear phase-out on electricity prices for industry and households and on CO_2 emissions. Neither do we investigate the question of energy security nor do we analyse the requirement and the additional costs for new transmission lines, storage capacities and investments into renewable capacities. In that sense, the analysis only focuses on the isolated effect of the nuclear phase-out and not on the challenges of the broader idea of the energy transition towards a “road into the age of renewables” (Federal Government, 2010).

The paper is organized as follows. In section 2, we present the scenario set-up, the electricity market model and evaluate the effect of the nuclear phase-out on electricity prices and CO_2 emissions. In section 3, we accomplish this with a sensitivity analysis and a comparison with results from other studies. Section 4 evaluates the effects of Germany’s nuclear phase-out on European electricity and CO_2 prices. Section 5 investigates the question whether Germany can do the energy transition alone or to what extent it relies on a European perspective. Section 6 concludes the findings.

2 Impact on electricity prices and CO_2 emissions

2.1 Scenario definition and model description

For exploring the different pathways, an assessment of different scenarios is required. We define them along the year of the nuclear phase-out and the different technologies by which nuclear capacities are to be replaced, i.e. gas or coal power plants. Both aspects were most heavily debated at the time shortly after the nuclear accident in Fukushima Daiichi in March 2011. The full set of scenarios is shown in Table 1.

Table 1: Scenario definition

Scenario Name	Exit year	Replacement by conventional power plants based on …
Exit2015-gas	2015	gas
Exit2015-coal	2015	coal
Exit2020-gas	2020	gas
Exit2020-coal	2020	coal
Exit2022	2022	combination of gas and coal
Exit2038	2038	combination of gas and coal

Regarding the development of renewable capacities, we assume the deployment path described in Nitsch et al. (2010) for all scenarios. It breaks down to an increase in renewable energies from 165 TWh in 2015 to 360 TWh in 2030 leading to a share of renewable energies in the electricity mix of 65% by 2030. Our assumptions for electricity demand, electricity production from renewable energy sources (RES), fossil fuel and CO_2 prices are based on the same study (price path B). The full set of assumptions is shown in Table 2.

Table 2: Exogenous input assumptions to the model. *The gas price refers to the border price.

	2015	2020	2025	2030
Gas price* [€/MWh]	27.4	30.6	34.2	37.1
Coal price (hard coal) [€/MWh]	12.6	14.4	15.8	16.9
CO_2 price [€/tCO_2]	26.0	31.2	34.3	36.4
Electricity production from RES [TWh/yr]	165	227	293	360
Gross electricity consumption [TWh/yr]	575	560	550	550

All scenarios are analysed with regard to the development of electricity prices and CO_2 emissions using the MICOES (Mixed Integer Cost Optimization Energy System) model. MICOES is a bottom-up electricity market model for power plant scheduling based on Theofilidi (2008) with an extension by Kondziella et al. (2011), Bruckner et al. (2010), Harthan et al. (2011). From a methodical point of view, MICOES is a mixed-integer optimization model that is capable to consider short term marginal cost, start-up and shut-down costs as well as limited ramp rates. It uses a least-cost approach to optimise the hourly scheduling of the conventional fleet of power plants in the market. Going beyond a simple merit order approach, it is therefore able to take into account the constrained flexibility of conventional power plants. Renewable generation serves as an exogenous input and hourly fluctuations by intermittent sources like wind and solar power are taken into account. More details concerning the input assumptions and the modelling approach are given in Knopf et al. (2011a) and Knopf et al. (2011b).

2.2 Projection of conventional replacement capacity

A complete withdrawal from nuclear energy in Germany means that 21 GW in net power plant capacity have to be replaced until 2022 (see Figure 1). The first eight out of 17 nuclear power plants that were taken off the grid by March 2011 (the so-called “Moratorium on nuclear energy”, Federal Government 2011) so that around 10 GW in power plant capacity were out of operation in mid 2011. This capacity was replaced by making use of existing overcapacity as well as by reducing net electricity exports. Furthermore, according to the German Association of Energy and Water (BDEW) (BDEW 2011b), a series of fossil fuel-fired power plants are under construction whose capacity of around 11 GW, mainly coal-fired power plants, will be available by 2015. This was taken into account by the model-based analysis. In this way, the capacity of the nuclear power plants could be completely replaced by 2015. However, it is also planned to shut down 14 GW in power plant capacity from old fossil fuel-fired power plants. And by 2020, a further 13 GW in fossil fuel-fired power plant capacity are to be shut down. This means that, in addition to the exit from nuclear energy, a total of 27 GW in fossil fuel-fired power plants will have to be replaced within the next decade. The options primarily deployed in our model for filling this gap include the expansion of renewable energy and of (centralized and decentralised) cogeneration capacity, the reduction of electricity demand by increasing energy efficiency and the import (although only for a limited number of hours per year) of electricity from other European countries. Apart from these replacement options the construction of fossil fuel-fired power plants or the refurbishment of older fossil fuel plants has to be considered. Based on economic considerations and our model-based analysis, 8 GW of additional conventional capacity is required (see Figure 2)

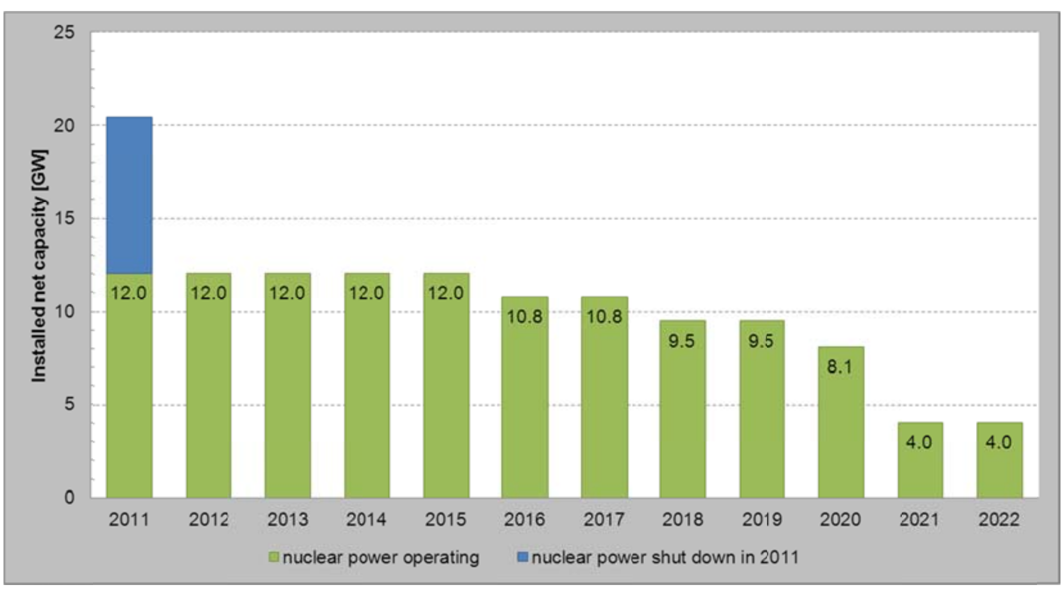

Figure 1: Nuclear power plants in operation. Eight of them (all built before 1981) were already shut down after the Moratorium in March 2011

The scheduling of the capacity expansion can be deferred further into the future depending on the date of exit (Figure 2). This means, e.g. in the case of a nuclear exit in 2020, not only all the power plant capacities currently under construction need to be ready, but that further fossil fuel-fired power plants currently planned or to be planned will have to be put into service. Alternatively, a prolonged use of older coal-fired power plants may be considered. An even earlier exit in 2015 would represent an even greater challenge and would probably endanger energy security. This involves many other open questions and assumptions requiring further investigation that is beyond the scope of this paper.

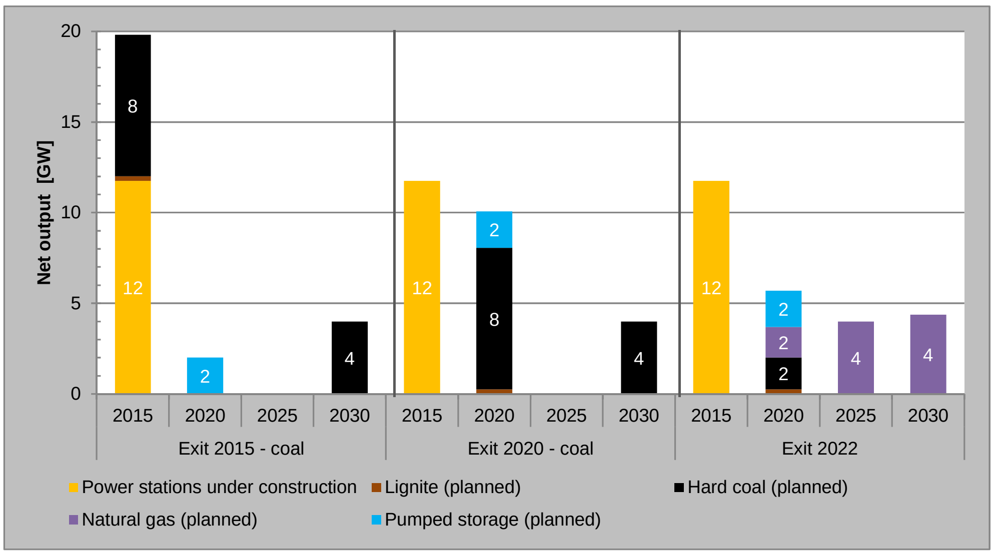

Figure 2: Replacement capacity required in conventional power plants. Comparison of scenarios *Exit2015-coal, Exit2020-coal* and *Exit2022*

2.3 Impact on electricity prices

Within liberalised electricity markets, spot market prices are based on the supply-cost curve (merit order) of all plants in the market. The marginal plant, i.e. the plant with the highest (short-term) generation costs still needed to meet a given demand, establishes the spot market price. Accordingly, nuclear energy, with low generation costs, would be the economically preferred technology within the merit order followed by lignite, hard coal and gas-fired power plants.

If nuclear power plants are to be decommissioned, the spot market price will rise in average in response, at least temporarily, since then more cost-intensive technologies are needed to cover the demand. The increasing proportion of renewable energy in the German electricity mix (40 % in 2020, 65 % in 2030 according to the Government's decision (Federal Government, 2010) will work in the opposite direction, bringing about a long-term fall in the spot market price level. The reason is that, in accordance with the feed-in-tariff system (and the low short term generation cost), renewable energy must be supplied at "negative" cost at the wholesale market in order to be able to ensure the obligation of grid operators to purchase all renewable energy and sell it to the market. As a result, the spot market price will rise until 2020 but then fall again to below the initial level by 2030 due to the ever increasing proportion of renewable energy (Figure 3).

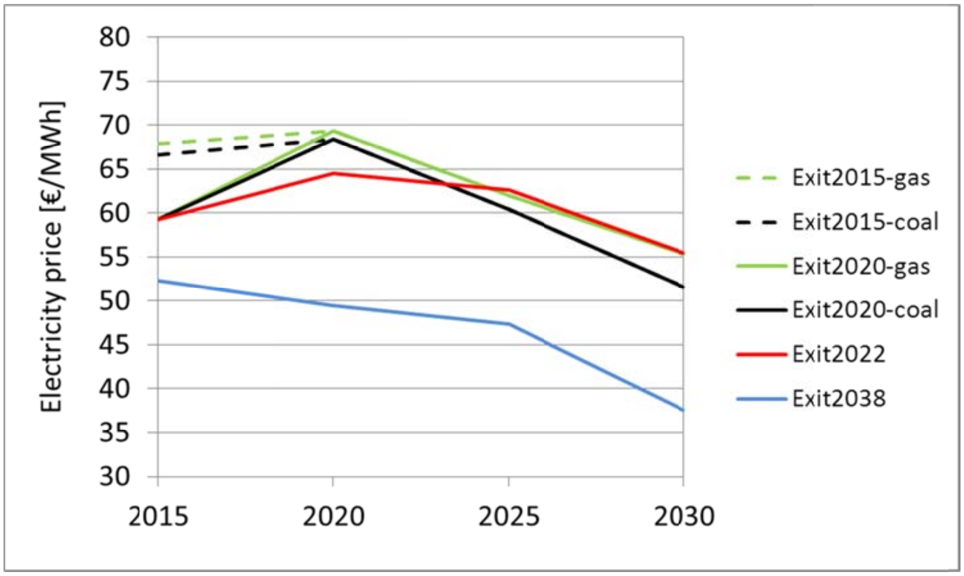

Figure 3: Development of the electricity price at the spot market (baseload). For comparison: The average price at the spot market (baseload) was 56 €/MWh in 2011

For the scenario *Exit2015-coal*, the spot market price in that year would be 67 €/MWh and thus 8 €/MWh higher than the price in the corresponding year in the case of an exit in 2020 or 2022. The reason for this is the need to draw on cost-intensive replacement capacities ahead of time. However, prices in the *Exit2015-coal* scenario are not higher in 2020 than those of the *Exit2020-coal* scenario since replacements only occur a few years later but still before 2020 (cf. Figure 2). In the case of *Exit2022*, replacements are put back a bit further so that the prices in 2020 will be 4 €/MWh lower. Long-term spot market prices, however, remain slightly lower in the case of an early exit with coal (*Exit2020-coal*) as the replacement option than under the *Exit2022* scenario. This is due to the intensified expansion of gas-fired power plants in the case of *Exit 2022* (Figure 3) which have a slightly higher cost level.

Furthermore, the results show that prices will reach nearly equal levels if nuclear power plants are replaced by either gas or coal-fired power plants. The reason is that, on the basis of the assumed fuel and CO_2 prices, electricity production costs for both technologies are approximately equal. Accordingly, if – apart from the projects under construction – exclusively gas-fired power plants are built instead of coal-fired power plants, for the scenario *Exit2020-gas* the spot market prices in 2020 will be only around 1 €/MWh higher than those under the scenario involving intensified expansion of coal-fired power plants *Exit2020-coal*.

Figure 3 also makes clear that a life-time extension of nuclear power (*Exit2038*) would have led to much lower wholesale prices and would thus have indeed facilitated the "road into the age of renewable energies" (Federal Government, 2010) by reducing costs. In numbers, there is a price increase of 11% between *Exit2038* and *Exit2022* in 2015 and 23% in 2020.

2.4 Electricity prices for household consumers

The prices for household consumers are determined only to a minor extent by the wholesale market price and the distribution that make up only about 35% of the overall consumer price (BDEW 2012a). Another important component is the feed-in-tariff (FIT) levy which makes up around 9% of the consumer price. The German FIT levy which is paid by all electricity consumers with some exceptions for electricity-intensive industries is based on the difference between compensation under the FIT system and the average electricity procurement costs on the electricity exchange. Thus, a price increase on the spot market is compensated by a reduced FIT levy for the end consumers. For the following analysis, the further end user price components, i.e. grid charges (~22%) and taxes (~24%), are assumed to be constant over time.

As electricity prices for households are given in units of ct/kWh, e.g. at the electricity bill, we refer in this section to this unit (1 ct/kWh equals 10 €/MWh). The maximum difference of end user prices is to be found in 2015 at 1.2 ct/kWh (between *Exit2015-gas* and *Exit2038*), see Table 3. In the case of average household use of 3,500 kWh per year this means additional costs of 3.5 € per month. The price difference between *Exit2020-gas* and *Exit2015-gas* of 0.7 €ct/kWh amounts to around 2 € per month. In 2020, the price difference at the household level of the scenario *Exit2022* and *Exit2038* comes to 0.2 ct/kWh or 0.58 € per month for the average household.

This let us conclude that for households liable to the feed-in tariff system the timing of the exit from nuclear energy will have little effect on electricity prices. But industrial consumers that are exempt from the FIT levy will be harder hit by the medium-term increase in the spot market price. If existing billing procedures are retained, however, there will be the possibility of benefiting from the price-dampening effect of renewable energy over the long term.

	Model results		Assumptions		Sum
Scenario	**Wholesale price [ct/kWh]**	**FIT levy [ct/kWh]**	**Taxes, network charges, etc. [ct/kWh]**	**VAT (19%) [ct/kWh]**	**Household consumer price [ct/kWh]**
Prices in 2015					
Exit2015-gas	6.79	2.49	9.51	3.57	22.4
Exit2020-gas	5.92	2.82	9.51	3.47	21.7
Exit2022	5.92	2.82	9.51	3.47	21.7
Exit2038	5.24	3.08	9.51	3.39	21.2
Prices in 2020					
Exit2015-gas	6.94	2.42	9.51	3.59	22.5
Exit2020-gas	6.94	2.42	9.51	3.59	22.5
Exit2022	6.45	2.74	9.51	3.55	22.2
Exit2038	4.94	3.49	9.51	3.41	21.4

Table 3: Electricity prices for household consumers in 2015 and 2020 (in real terms 2007). 1ct/kWh equals 10 €/MWh

2.5 Impact on CO_2 emissions

The year of the nuclear phase-out has a clear impact on CO_2 emissions (see Figure 4) as the substitution with coal-fired power plants or gas-fired power plants the CO_2 emissions of the electricity generation sector would increase. The earlier the phase-out, the higher are the emission at least until 2025. In the long term, however, for the scenarios *Exit2015*, *Exit2020* and *Exit2022*, the emissions would be similar. An exit in 2020 instead of 2022 would of course mark only a short-term rise in CO_2 emissions (Figure 4). Nonetheless, a complete exit in 2015 would increase CO_2 emissions: In 2015, they would be 64 $MtCO_2$ higher than in the case of *Exit2020* or *Exit2022*. The additional emissions could be reduced by 20 % if the expansion of gas-fired power plants was pursued instead of coal-fired power plants. An increase of 64 $MtCO_2$ would raise German CO_2 emissions of the electricity sector by almost a quarter in 2015.

A life-time extension of nuclear power until 2038 would have reduced emissions in Germany by 45 to 70 $MtCO_2$ between 2015 and 2030 but the *Exit2022* scenario still reaches roughly 70% reduction against 1990 by 2030 solely in the power sector. In fact, the German nuclear energy phase-out in 2022, as consensually enacted in 2011, only means a return to the old “status quo” before the prolongation of the operational life of nuclear power plants in autumn 2010. Climate protection is not endangered by the earlier phase-out since the total quantity of emissions in the European electricity sector is limited by the cap of the EU emissions trading system that was set up in 2005 when the decision on the first nuclear phase-out in Germany was already taken. In that sense, the nuclear phase-out has no effect on the overall CO_2 emissions of the EU. The CO_2 emissions from the power sector are capped under the EU ETS. This means that larger emissions in one region are offset with lower emissions in a different region. This may indeed affect the regional distribution of CO_2 emissions across the EU but not the overall emissions.

Nevertheless, increasing emissions can lead to an increase in CO_2 prices, see section 4. This would mean that across Europe, power plants would be utilised that emit less CO_2. Since nuclear power plants have lower marginal costs, their capacities are, as a rule, already fully utilised within the framework of the existing possibilities. Rising CO_2 prices would therefore lead mainly to the utilization of more efficient fossil fuel-fired power plants across Europe.

Our analysis solely focuses on the electricity sector but the emission path is very much in line with that of the Nitsch et al. (2010) that reaches an economy-wide emission reduction of 85% by 2050 with CO_2 emissions from the electricity sector accounting for 213 $MtCO_2$ in 2020 and 105 $MtCO_2$ in 2030 compared to 188 and 113 $MtCO_2$ in our scenario *Exit2022*. This gives an indication that Germany may be able to still achieve its domestic targets, i.e. a CO_2 reduction of at least 80% by 2050 even with a nuclear phase-out by 2022.

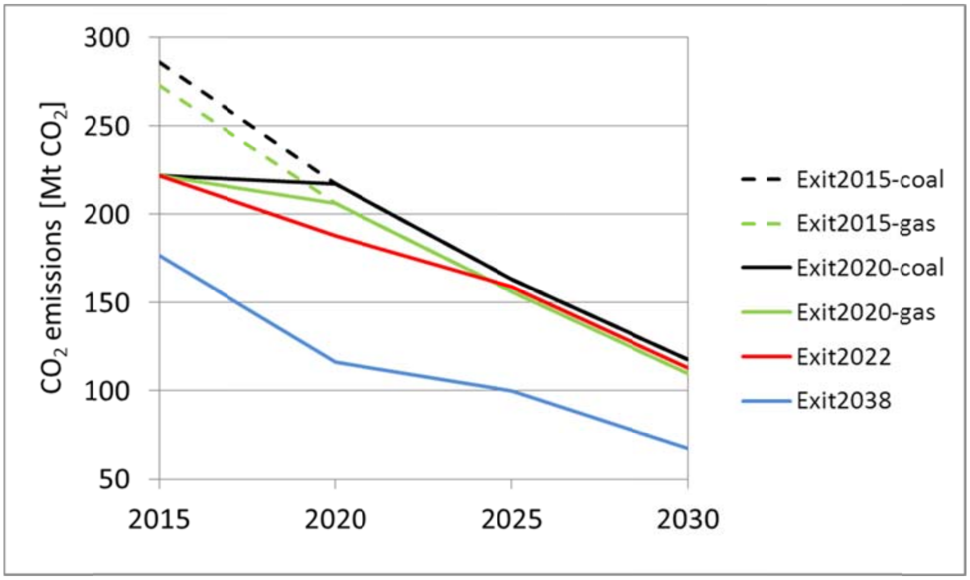

Figure 4: CO_2 emissions from conventional power plants 2015–2030

3 Sensitivity analysis and comparison with other studies

The results of the model given in section 2 are determined to differing extents by the initial assumptions. Within the framework of a sensitivity analysis, the following assumptions were considered: a) fossil fuel and CO_2 prices that are rising stronger compared to the default assumptions; b) failure to achieve efficiency targets (and a constant electricity consumption at today's level as a result of that); c) more modest expansion of decentralised cogeneration; d) increased flexibility on the demand side by means of demand-side management measures (DSM); e) a more rapid expansion of renewable energy (see Table 4).

The largest influence on spot market prices is exercised by the assumption about the future development of fossil fuel and CO_2 prices which, in comparison to the scenario *Exit2020-gas*, lead to a 25 % increase from 69 to 86 €/MWh in 2020. The reason for the large influence of the fossil fuel price and especially the gas price lies in the merit order (see section 2.3). As in most cases, the power plant with the highest (short-term) generation costs is a gas turbine, the gas price therefore has a large influence on the spot price.

The assumption of a rise in energy efficiency also exerts a big influence. If electricity consumption, contrary to policy targets, remains at its current level, wholesale prices will increase by 10 %. The influence of these assumptions on the electricity price is thus similar to or even greater than the timing of the exit itself, compare Figure 3. In contrast, the impact of load shifting measures (demand-side management) can reduce prices only slightly: Likewise less cogeneration has also a relatively low impact on prices. Again, as already explained in section 2.4, the influence on the price for households is very limited, the spread is between 22.3 ct/kWh (with DSM) and 23.5 ct/kWh (for high fossil fuel and CO_2 prices), i.e. only an increase of 4%.

	Spot market price (baseload) in 2020 [€/MWh]
Reference scenario: Exit2020-gas	69
Sensitivities:	
Higher fuel and CO_2 prices	*86 (25%)*
Constant instead of decreasing electricity consumption	*76 (10%)*
Only modest expansion of decentralised cogeneration	*72 (4%)*
More rapid expansion of renewable energy	*66 (-4%)*
Demand-Side-Management	*68 (-1%)*

Table 4: Sensitivities in relation to spot market prices (baseload) in 2020 with regard to the scenario *Exit2020-gas*.

As the sensitivity analysis shows, the assumptions have a strong influence on the electricity prices that is even stronger than the exact year of the phase-out. Therefore, it can be expected that other studies likely differ in their projected price paths – given different assumptions. We compare our results (labelled as PIK/IIRM in Figure 5) with results from other studies that analyse a phase-out in 2022 compared to a phase-out in 2038. These studies are enervis energy advisors (2011), Prognos/EWI/GWS (2011), IER/RWI/ZEW (2010) and r2b energy consulting/EEFA (2010).

Whereas the difference between a phase-out in 2022 and a life-time extension until 2038 leads to differences in wholesale prices between 6 €/MWh in 2015 and 17 €/MWh in 2030 (see Figure 5, cf. also German Council of Economic Experts (2011)), the absolute numbers show a very large divergence between the studies (see Figure 6a) as large as 26 €/MWh already in 2015. This means that the differences in absolute price levels between the different studies are much larger than the relative differences between the scenarios with and without a life-time extension of nuclear power.

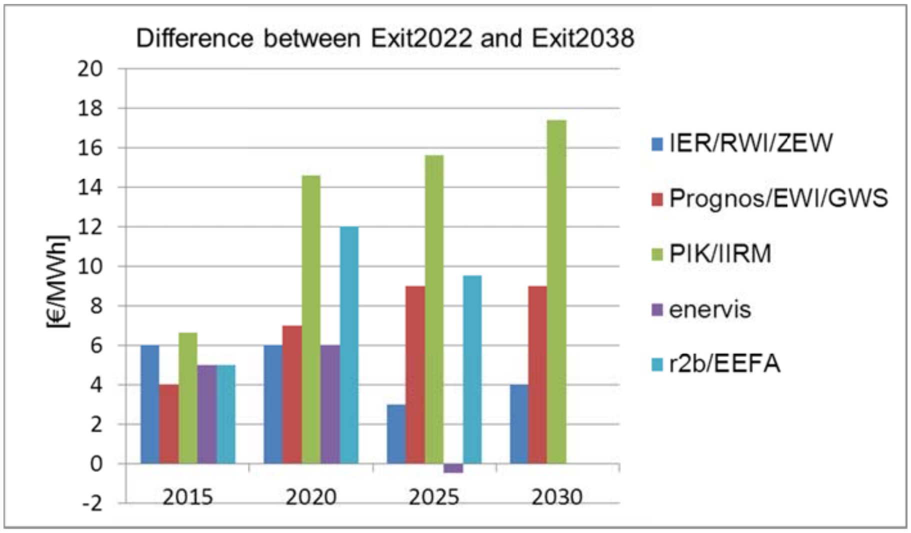

Figure 5: Difference in wholesale prices between a nuclear phase-out in 2022 and 2038 for different studies. For enervis a comparison between 2020 and 2038 is shown. PIK/IIRM refers to this study

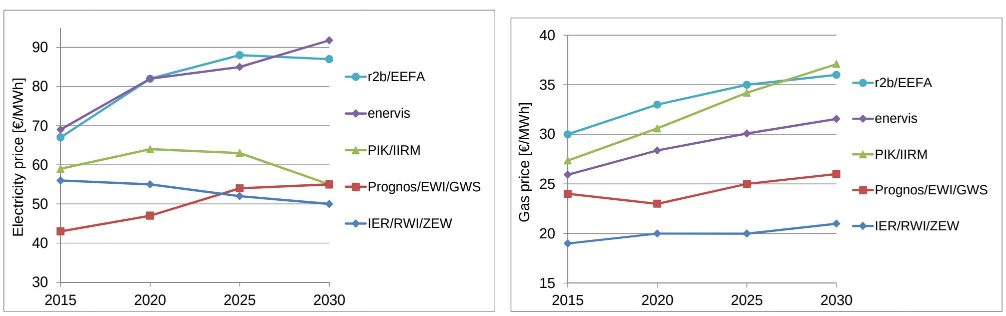

Figure 6: a) Wholesale prices for a nuclear phase-out in 2022 for different studies. Enervis shows a phase-out in 2020. b) Assumption on the gas price in the different studies. PIK/IIRM refers to this study

The price path for the different studies does not only show a large divergence in absolute numbers but also the tendency of increasing (in three studies) or decreasing prices (in two studies) is not clear. In Knopf et al. (2012), the reasons for these differences are analysed in more detail. It turns out that the studies are based on very different assumptions concerning i) fossil fuel and CO_2 prices, ii) the deployment path of renewable energies and iii) the future electricity demand.

The gas prices show an increase in all studies but differ as much as 11 €/MWh in 2015 which is nearly 50% of the price level of 20.6 €/MWh that was observed in 2010, see Figure 6b. As mentioned before, due to the merit order, the gas price has a strong influence on the electricity price so it is not astonishing that electricity prices are so different given the widely differing assumptions on the future gas price development. The same holds for CO_2 prices (that are an input in all models) that show a range between 15 and 40 €/tCO_2 already in 2015. As seen in the sensitivity analysis, energy efficiency - represented by the reduction of electricity demand - is also an important driver for the electricity prices. Whereas the demand decreases in three studies (PIK/IIRM, Prognos/EWI/GWS and r2/EEFA), it increases in the two others (IER/RWI/ZEW and enervis). This partly explains the low prices for PIK/IIRM and Prognos/EWI/GWS. The decreasing prices for PIK/IIRM can mainly be explained by the assumption of a very ambitious deployment path for renewable energies along the numbers in Nitsch et al. (2010) that reaches 360 TWh in 2030, whereas in the other studies only between 212 to 267 TWh are reached.

The sensitivity analysis and the comparison show that many other factors besides the decision of the nuclear phase-out determine the electricity prices. Some of them can be influenced by political decisions and regulatory frameworks, e.g. energy efficiency, but others, mainly gas and CO_2 prices, cannot be controlled by government decisions. This is even more critical as the latter drivers have a larger influence on the electricity price than the nuclear phase-out itself.

4 Impact of Germany’s phase-out on European prices

Although Germany’s decision on the nuclear phase-out was taken at the national level, its impacts are clearly Europe-wide. Some EU member states therefore heavily criticized the German solo attempt concerning the phase-out (RP Online 2011, FTD 2011, Spiegel Online 2011, Sverigesradio 2011, ZEIT 2011). But despite the fact that the EU Commission came out with their *Energy Roadmap 2050* in December 2011 (European Commission 2011a) that is seen as “the basis for developing a long-term European framework”, the energy mix is still a national business. The EU treaty, Article 194, states that “in the context of the establishment and functioning of the internal market and with regard for the need to preserve and improve the environment, the Union policy on energy shall aim, in a spirit of solidarity between Member States, […] to ensure security of energy supply in the Union” (Council of the EU, 2008). In the same article, however, it is also stated that such measures “shall not affect a Member State's right to determine the conditions for exploiting its energy resources, its choice between different energy sources and the general structure of its energy supply” (Council of the EU, 2008). So on the one hand, energy supply is a national issue but on the other hand the “spirit of solidarity between Member States” is stressed. In this light, what does Germany’s shutdown of seven nuclear power plants of March 2011 and the planned phase-out of all 17 nuclear plants by 2022 mean for the other Member States? Three effects shall be analyzed in this context: First, the effects of the German nuclear moratorium on the short-term and longer-term European electricity prices and furthermore the effects on cross border electricity trade, second, the effect on the CO_2 price and finally the effect on the overall emissions in the EU.

At the day of the announcement of the moratorium (14 March 2011), the prices for the German baseload futures (2012 delivery) increased sharply by 6-8 €/MWh (BDEW 2011a). The price increase may have reflected the expectations of market participants that the capacity gap from eight nuclear power plants would be replaced by fossil plants with higher marginal production costs. However, around four months later prices dropped back to their original level. One year after the moratorium, there is no visible effect on electricity price futures. The price for the German 2013 baseload future before the moratorium and one year later were both traded around 53 €/MWh (EEX 2012a). This indicates that the expectations by market participants on future prices were equivalent before and after the moratorium and the final decision on the phase-out. Germany is part of an electricity market that includes all its neighbours. The effects of the moratorium were therefore visible in similar magnitude in neighbouring states which is illustrated by the example of France. The price of the French baseload future (2012 delivery) increased by roughly 8 €/MWh after the announcement of the moratorium (see Figure 7). Analogous to the German baseload future, after around four months, the prices reverted to their original level, probably mainly due to the economic downturn and the related decrease in electricity demand. The trade surplus for electricity between Germany and its neighbours decreased from 16.9 billion kWh in 2010 to 6.3 billion kWh in 2011 which is a reduction of 63% (see Table 5, BDEW 2012a). This decrease in exports is simply due to the fact that one replacement option for nuclear is the reduction of electricity exports. Hence, it can be stated that the announcement of the German nuclear phase-out triggered a significant short-term effect on Germany's and its neighbours' electricity prices. However, one year after the moratorium, there is no evidence of a lasting price increase. The latter result, however, is tentative due to a missing counterfactual and should be checked e.g. for cases of extreme events, e.g. such as the cold February in 2012 in combination with an under-supply of gas in Southern Germany (BNetzA 2012).

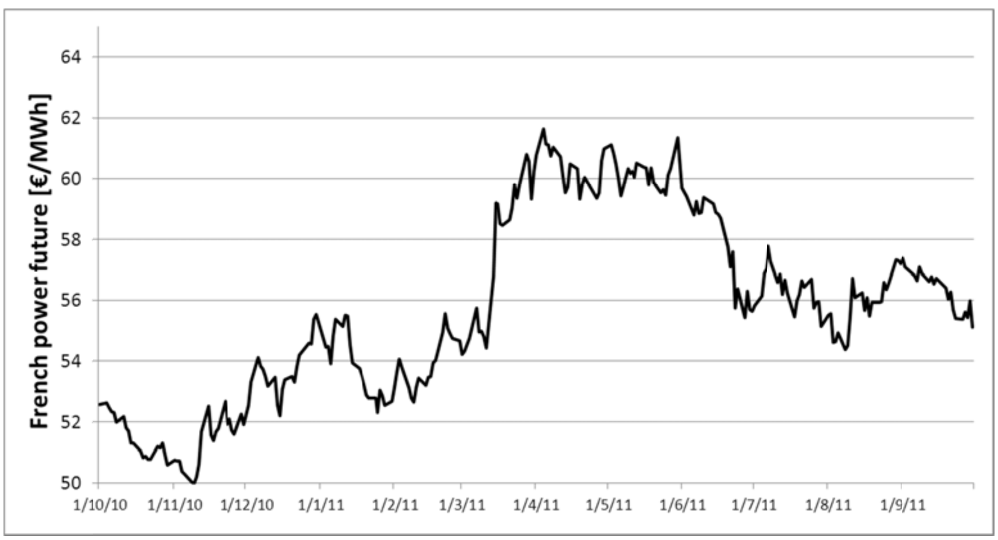

Figure 7: French power futures (Cal-12). Source: EEX 2012d

	Imports to Germany		Exports from Germany		Balance
	Million kWh	Change from previous year in %	Million kWh	Change from previous year in %	Million kWh
France	20 313.0	+ 34,3	139.0	-82.5	+ 20 174,0
Czech Republic	9 408,0	+ 0,1	1 886,0	+ 234,4	+ 7 522,0
Austria	6 356,0	- 20,7	15 9230	+ 8,3	-10 567,0
Denmark	5 055,0	+ 86,6	2 910,0	- 55,0	+ 2 145,0
Netherlands	3 219,0	+ 4,8	9 589,0	+ 7,2	- 6 370,0
Switzerland	2 762,0	+ 7,0	14 000,0	- 3,8	- 11 238,0
Sweden	2 047.0	+ 103,3	628.0	-73.3	+ 1 419,0
Luxembourg	1 154,0	- 15,2	5 818,0	-5.5	- 4 664,0
Poland	433.0	+ 159,3	5 138,0	- 3.7	- 4 705,0
Sum	**49 747,0**	**+ 18,0**	**56 031,0**	**-6.4**	**- 6284,0**

Table 5: Physical electricity trade between Germany and its neighbours 2011. Source: BDEW (2012a)

Analogous to the electricity price, the effect of the nuclear moratorium on the CO_2 price shall be analyzed. After the announcement of the moratorium, the price for CO_2 certificates on the spot and the future market increased by 1-2 €/tCO_2 (EEX 2012b, EEX 2012c, BDEW 2011a, Öko-Institut 2011). The price increase for CO_2 certificates may have been caused on the one side by the expectations of German fossil plant operators to substitute the nuclear electricity by conventional power plants and furthermore by foreign operators of conventional fossil power plants that expected higher exports to Germany (BDEW 2011a). However, the price spike lasted only for a brief period. In the longer term, the CO_2 price is decreasing. Already three month after the moratorium the price was back to its initial level of € 15/tCO_2 and from then on, the certificate price kept falling to 9 €/tCO_2 in February 2012 (EEX 2012b). However, this price drop is probably owed to factors such as the economic downturn and the oversupply of certificates in the EU ETS (Öko-Institut 2012). It can be stated that the moratorium caused a short-term price increase, however, there is no empirical evidence for a longer-term price increase for CO_2 certificates.

An increase in the CO_2 price can have an effect on the generation mix in other EU countries since less CO_2-intensive generation facilities such as gas turbines become more competitive and replace coal power plants. However, it is unlikely that the German nuclear phase-out did cause a longer-term price change because when the CO_2 budgets for the second and third trading period (2008-2020) were negotiated, the “old” decision on the nuclear phase-out of 2000 was still in effect. The extension of the operating lifetime that was passed by the conservative coalition in fall 2010 was in effect only for half a year until June 2011. Planning of power plants is characterized by long lead times. It is unlikely that the six-month-intermezzo of the extension of the operating lifetimes had much influence on the planning of the generation mix of other EU member states.

5 Can Germany do the energy transition alone?

In the discussion on the German nuclear phase-out, the bigger picture has often been lost out of sight. While the nuclear phase-out is a discussion on short and medium-term replacement capacities, the energy transition is a long term endeavour with the goal to reduce CO_2 emissions by 80-95% by 2050 and to enable a “road into the age of renewable energies” by raising the share of electricity generated from renewables to 80% by 2050 (Federal Government 2010). To this end, a relevant question is whether Germany can do the long-term energy transition alone. In the following, we will argue that in the mid-term, Europe will become of major importance for the transformation in Germany (cf. Fischer and Geden, 2011). Managing the energy transformation in Germany and keeping the costs at an acceptable level depends on a coordinated strategy to support renewable energies in Europe.

A strong argument for integrating the German energy transition into a broader European perspective is based on the observation that model results indicate that a pure domestic approach for reducing CO_2 emissions could become more costly compared to a situation where other mitigation potentials are used in Europe. Schmid and Knopf (2012) show that pursuing a pure national strategy and waiving of mitigation options outside Germany can lead to a non-linear increase in mitigation costs with more ambitious CO_2 reduction targets especially when the renewable potential should appear to be small. This implies that it could be more cost-efficient to mitigate some part of the CO_2 emissions outside Germany, e.g. on the European level by means of the EU ETS.

The limited mitigation options in Germany finds an expression in the model results as a number of energy scenarios for Germany (e.g. Nitsch et al. 2010, Schlesinger 2010) assume an increasing exchange of (renewable) electricity with other European countries towards the mid of the century. Results indicate that in most cases the electricity import balance will be positive by 2050, i.e. Germany will change from a major exporter of electricity (17.8 TWh in 2010 (BMWi, 2012)) to a net importer. In Nitsch et al. (2010) up to 200 TWh are imported in 2050, which corresponds to 22% of total demand. Also Schlesinger et al. (2010) show an import of at least 100 TWh in 2050, i.e. 25% of total demand in their study. These imports are exclusively (Nitsch 2010) or to the better part (Schlesinger 2010) from renewables and considerably help to achieve the German long-term target for the renewable deployment of 80% share in electricity by 2050. This points out that a transition in other European countries is implicitly assumed and required to foster the German energy transition. This implies that deployment of renewable energy sources in other European countries must develop accordingly and that a political and institutional framework capable to arrange required imports must be in place. It goes without saying that this requires further European coordination likely beyond the current level.

Increasing the share of renewables in Germany additionally faces some technical problems where a stronger interconnection within Europe could help (Haller et al. 2012). The high natural fluctuations from renewables can partly be balanced out in a larger market. In a large geographical region, the weather varies. If the wind is calm in Germany, the sun may shine in Spain and the other way around. This follows the logic that the larger the connected market area, the lower the fluctuations of supply. To reap the benefits of this effect, sufficient grid interconnections are necessary. In the past, the interconnectors to neighbours were limited. However, the aim of a fully integrated internal energy market across the EU has already induced initiatives for grid expansions. The provisions of the third internal market package and the directive EC 714/2009 (European Parliament 2009) lead the way towards better interconnections across the EU (ENTSO-E 2010).

As argued above, the EU ETS becomes therefore a crucial element for a German mitigation strategy. With the EU ETS, CO_2 is avoided where it is cheapest and therefore it also enables cost reduction of mitigation not only in Germany but in all European countries. Therefore, the further development of the EU emissions trading system is extremely important for future climate and energy policy. The EU Emissions Trading System is the EU’s central climate policy instrument. However, to date the EU ETS covers only around 40 per cent of the EU’s greenhouse gas emissions, namely in the areas of electricity generation and industry. From an economic point of view, it would make sense to regulate emissions to the furthest extent possible under the ETS. The next candidate for inclusion in the ETS is transport (e.g. Flachsland et al. 2011) but integration of the residential sector would also be reasonable. The end result of this development should be that all sectors are included. Inclusion of these sectors would reduce the costs of climate protection because the search for the most efficient mitigation measures would then be extended to sectors and countries in which particularly high cost savings can be assumed. In doing so, this would not only reduce the costs in Germany but for every European country and would make the transition overall cheaper compared to the situation where every country pursues a pure national approach.

These examples show that Germany can most probably not do the transition alone, at least not in the long-term, and that on the contrary it relies in several aspects on the success of a transition in Europe, e.g. concerning electricity imports and the further development of the EU-ETS. In that sense, a better coordination towards a European strategy of the energy transformation would not only foster the German energy transition but could also decrease the costs of the European aim to reduce CO_2 emissions of 80-95% by 2050 (European Commission 2011b) for all member states.

6 Conclusions

The model analysis with the electricity market model MICOES shows that the nuclear phase-out has a visible effect on the wholesale electricity prices that will increase compared to the situation with a life-time extension of nuclear power by 11% in 2015 and 23% in 2020. On the other hand, uncertainty in some input assumption, such as the development of the gas price or energy efficiency, has a stronger effect than the year of the nuclear phase-out. This implies that exogenous drivers and assumptions determine the electricity prices to a much larger extent than the phase-out itself. Prices for households are not very much affected by the phase-out but could be affected indirectly by rising prices for goods. CO_2 emissions will rise in Germany but due to the cap of the EU-ETS not in Europe.

From the comparison with other studies, we can conclude that different assumptions lead to a variety of developments of the electricity price which implies that the future development of electricity prices in Germany is highly unpredictable. For the time between 2015 and 2030, three out of five models show an increase in electricity prices while two show a decrease. The only exception is that at least a short-term increase until the nuclear power plants are replaced by new renewable or fossil capacities seems to be a robust result across all models. The sensitivity analysis has revealed that some assumptions have a huge influence on the model output, i.e. the electricity price. Whereas some of these assumptions, e.g. on energy efficiency, can be addressed by policy measures, some others, e.g. the gas price, cannot be influenced by national policies. This implies that policy-makers need to consider scenarios that analyze the whole range of possible future developments including a worst-case. For this endeavour, a structured model comparison with harmonized input assumptions, including also a worst-case scenario, is strongly needed. From such an analysis, robust pathways that are valid under a range of assumptions and across a range of models could be identified.

The empirical analysis about the influence of the German nuclear phase-out on the European scale lets us conclude that besides the short-term effects on CO_2 and electricity prices, the nuclear phase-out had rather small effects regarding these quantities on other member states. On the other hand, the long-term effect, e.g. during periods of extreme situations such as cold winters, cannot be figured out yet. Also the implications of a substantial decrease of electricity imports will show its effects only in the near future. So while the effect of the nuclear phase-out on other European countries does not seem to be tremendous, section 5 also made it clear that the energy transition towards a system with a high share of renewables will only be possible if this endeavour is embedded into a much broader European context given the substantial amount of electricity imports that are required in many scenarios and given the fact that a pure domestic approach of emissions reduction can become very costly.

As pointed out in the beginning, we concentrated here solely on the effect on electricity prices for industry and households and on CO_2 emissions. Neither did we investigate the question of energy security nor did we take into account the fact that massive investments into renewable capacities have to be realised over the next years, that the grid expansion has to happen with hundreds of kilometres of newly installed transmission lines, that social acceptance will become a major issue when the electricity supply will change from a very centralized supply system with only limited "hot spots" to a more decentralized system that will be closer to the people and many more effects. But these are the challenges of the entire "Energiewende", i.e. the transformation towards a "road into the age of renewables" and the influence of the nuclear phase-out on this challenge seems to be only one out of several – and probably not the biggest one.

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