THE CONSEQUENCES SO FAR OF GERMANY'S NUCLEAR PHASEOUT ON THE SECURITY OF ENERGY SUPPLY

A brief analysis commissioned by Greenpeace Energy eG in Germany

INTRODUCTION / PURPOSE OF THE STUDY

After the Fukushima nuclear disaster, the German government changed its energy policy and declared a nuclear moratorium on 14 March 2011. Germany's 17 nuclear power plants (NPPs) on the grid at that time underwent safety inspections and the seven oldest NPPs and the Krümmel NPP were shut down, initially for three months. The phaseout of nuclear power generation was then formally marked by the amendment of the Atomic Energy Act that entered into force on 6 August 2011. This change in legislation terminated the operating authorisation for eight nuclear power plant reactors and as a result, eight reactors with a significant level of net power generation capacity totalling 8.4 GW were taken off the grid on that day. This capacity is equivalent to approximately 10 percent of Germany's peak demand for electricity.

The amendment to the Atomic Energy Act also set dates for the final shutdown of each of Germany's remaining nuclear power plants in a schedule to be completed by 31 December 2022. Therefore, if a power plant generates its cut-off limit of electricity allotted by the Atomic Energy Act before this date, then it must be taken off the grid correspondingly earlier, whereby a transfer of the cut-off limit can be made to those NPPs that began operating at a later time. Figure 1 provides an overview of Germany's nuclear power plants and their final decommissioning dates.

Power Plant	Net capacity in MW	Operator	Commissioned on	Remaining term according to: cut-off limit for electricity production	Remaining term according to: decommissioning date as mandated by law
Biblis A	1,167	RWE	26.02.1975		06.08.2011
Neckarwestheim 1	785	EnBW	01.12.1976		06.08.2011
Biblis B	1,240	RWE	31.01.1977		06.08.2011
Brunsbüttel	771	Vattenfall	09.02.1977		06.08.2011
Isar 1	878	E.ON	21.03.1979		06.08.2011
Unterweser	1,345	E.ON	06.09.1979		06.08.2011
Philippsburg 1	890	EnBW	26.03.1980		06.08.2011
Grafenrheinfeld	1,275	E.ON	17.06.1982		27.06.2015
Krümmel	1,346	Vattenfall	28.03.1984		06.08.2011
Gundremmingen B	1,284	RWE	19.07.1984	15.03.2017	31.12.2017
Gundremmingen C	1,288	RWE	18.01.1985	14.01.2017	31.12.2021
Grohnde	1,360	E.ON	01.02.1985	11.10.2018	31.12.2021
Philippsburg 2	1,402	EnBW	18.04.1985	04.10.2018	31.12.2019
Brokdorf	1,410	E.ON	22.12.1986	13.09.2019	31.12.2021
Mülheim-Kärlich	1,219	RWE	01.10.1987		
Isar 2	1,410	E.ON	09.04.1988	26.02.2020	31.12.2022
Emsland	1,335	RWE	20.06.1988	12.01.2021	31.12.2022
Neckarwestheim 2	1,310	EnBW	15.04.1989	12.04.2022	31.12.2022

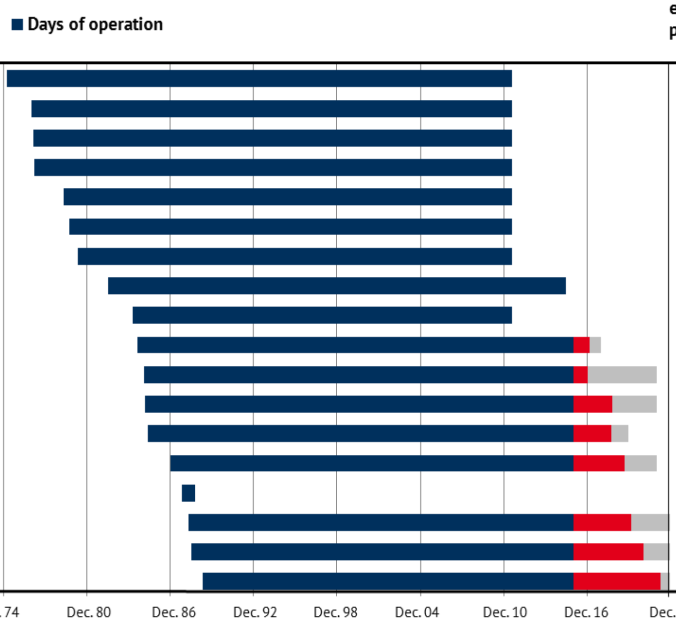

Figure 1: Overview of the lifetimes of German nuclear power plant reactors on 1 January 2016. (Sources: Atomic Energy Act of 6 August 2011 and own calculations)

The halfway point of Germany's phaseout of nuclear power has now been reached. Following the decommissioning in June 2015 of the Grafenrheinfeld NPP (with roughly 1.3 GW of installed capacity), another 10.8 GW of installed NPP capacity will be taken off the grid in the next six years until 31 December 2022 at the latest. At the same time as the nuclear phaseout has been ongoing, the share of renewable energies in electricity consumption, according to AG Energiebilanzen [Working Group on Energy Balances (AGEB)] (2016), has risen from 20.4 percent to 31.6 percent in the period from 2011 to 2015.[1]

In contrast, other European countries are building (Finland, France) or planning to build new NPPs or expand or replace existing ones (UK, Poland, Sweden, Czech Republic, Hungary). In the reasoning stated for these power plants, it is often argued that these NPPs are needed to guarantee the supply of electricity while keeping CO_2 emissions low.[2]

Given this background, the study will analyse the security of electricity supply in Germany while taking into account the country's nuclear phaseout and the parallel expansion of renewable power production.

DEVELOPMENT OF SUPPLY SECURITY IN GERMANY

The effect that phasing out nuclear energy has on the security of supply depends on many more factors than just the installed capacity of a given technology. This study will describe three different indicators of supply security that can be applied during the timeframe of the nuclear phaseout: the SAIDI index of supply security, the plan for guaranteed capacity, and the demand for balancing power. Nuclear power production is only one of several different factors that influence the security of supply in the electricity system. The purpose of the study is to investigate supply security according to power plant capacity, not to discuss the distribution of electricity within Germany.

THE SAIDI INDEX OF SUPPLY SECURITY

A central indicator of supply security is the System Average Interruption Duration Index (SAIDI). The SAIDI is published annually by Germany's Federal Network Agency and indicates the quality of supply by means of the average supply interruption per end consumer in minutes. Figure 2 shows index values for each year from 2006 to 2014.

When Germany's nuclear phaseout formally began on 6 August 2011, eight nuclear power plant reactors with a net installed capacity of altogether 8.4 GW were permanently taken off the grid on the same day. This deactivated NPP capacity was equivalent to 10 percent of Germany's annual peak load. However, during that year and the following year of 2012, the security of supply remained at a high level.

[1] Value for 2015 according to preliminary information.
[2] See European Commission (2016), The Telegraph (2016) for the UK, Tagesschau (2016) for Sweden, Pester Lloyd (2015) for Hungary.

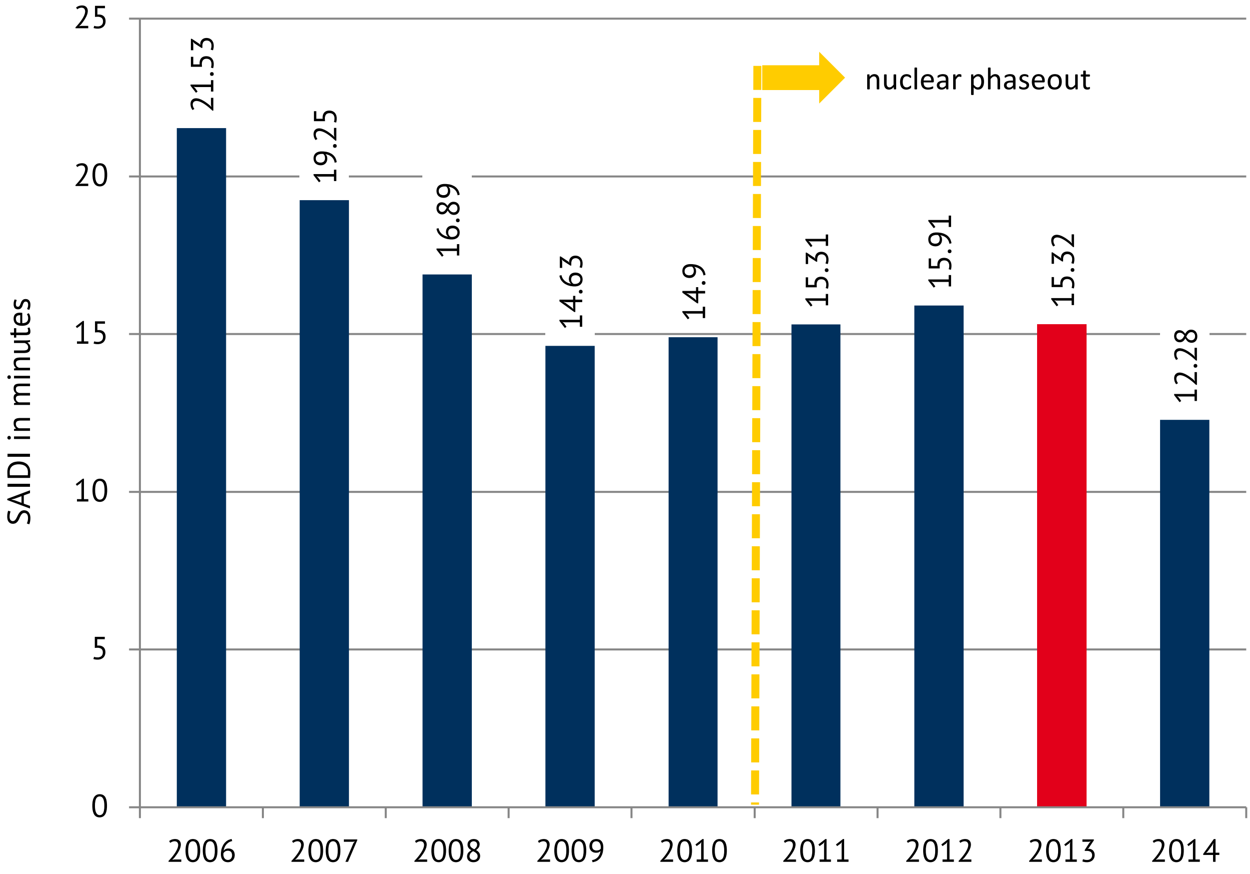

Figure 2: SAIDI values for Germany in an annual comparison. (Source: Federal Network Agency, 2015)

Although average supply interruption increased by one minute to 15.9 minutes from 2010 to 2012, this value was nevertheless about 30 percent lower than the statistic recorded in 2006. The Federal Network Agency (BNetzA) attribute the increase in the SAIDI in 2012 to a high increase in interruptions at the medium-voltage level caused by third parties[3] and to so-called retroactive disruptions[4] (BNetzA 2013). At the same time, the BNetzA excluded the energy revolution as a factor of significant influence regarding the quality of supply.[5] The increase in supply security in 2014, within the meaning of the SAIDI, was attributed in particular to fewer atmospheric effects caused by extreme weather conditions and fewer retroactive disruptions (BNetzA 2015a).

Some weather events can aggravate the supply situation at conventional power plants. During the hot summers of 2006 and 2007, some plants had to curtail output or even shut down entirely to avoid heating above permissible limits the river water used for cooling. In December 2015, low river levels at coal power plants led to breakdowns in power supply because these plants could not be supplied with coal by ship. The ENTSO-E report on supply security (ENTSO-E 2016) assesses Germany's overall risk of experiencing a supply deficit as low. Rather, the report says that Germany's grid faces the strain

[3] Caused by third parties means interruptions in supply that occur when persons, animals or vehicles come into contact with live power lines or that occur through digging or dredging (BNetzA 2015a).

[4] Retroactive disruptions are disturbances in an upstream or downstream network, in the facility of an end consumer, or an interruption in supply from plants feeding in power (BNetzA 2013).

[5] "*For the year under review, significant impact from the energy transition and an associated increase in decentralised production capacity on the quality of supply can thereby be ruled out*", said Jochen Homann, president of the Federal Network Agency (BNetzA 2013).

of handling too much electricity; facilities must reduce output more and more frequently to avoid critical situations.

The average supply interruption has fallen overall in Germany even during the nuclear phaseout period and was only about 12 minutes in 2014, which corresponds to 99.998 percent supply security. However, a high share of conventional production capacity (in nuclear power) alone does not guarantee having a high level of supply security, as the European comparison for 2013 in Figure 3 shows.

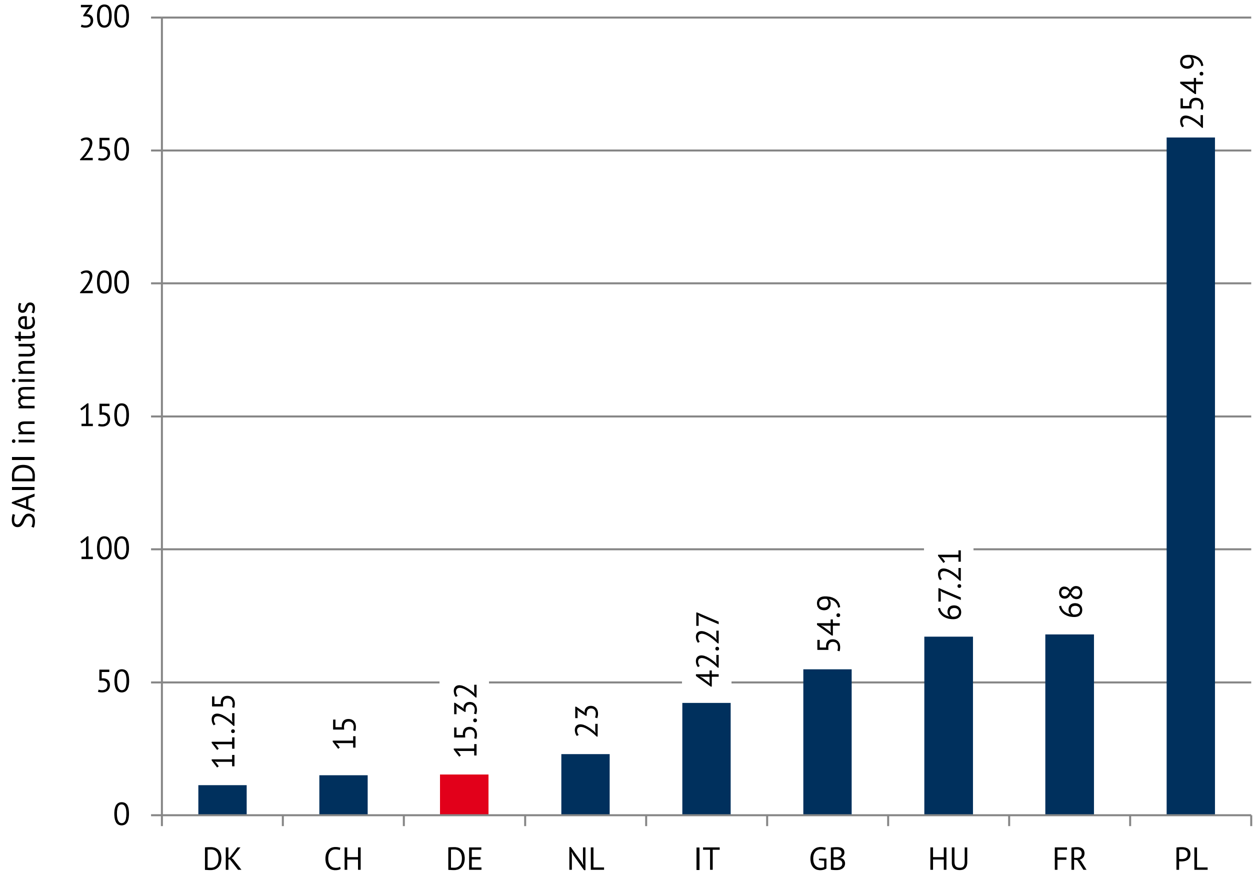

Figure 3: SAIDI values for 2013 in a European comparison. (Source: CEER, 2015)

For example, Switzerland, with a 39 percent share of power production from nuclear energy, achieved a comparatively short average supply interruption of 15 minutes in 2013, whereas the UK (19 percent), Hungary (36 percent) and France (81 percent) had considerably longer average supply interruptions of 55, 67 and 68 minutes respectively. Definitive for the degree of supply security is therefore not the share of a particular production technology in the system but rather the overall situation regarding production and the grid.

THE PLAN FOR GUARANTEED CAPACITY

A consideration of the present situation alone is not sufficient for assessing the security of supply. To ensure the future security of supply at a high level, a correspondingly installed power plant capacity must be available at the time of the highest demand for electricity. The following review assumes that grid expansion within Germany will be implemented as planned and that all delays and grid requirements will still be covered by the mechanics of grid reserves.

The plan for establishing guaranteed power plant capacity is shown in Figure 4. It is used for example in the *Leistungsbilanzbericht* [report on power balancing] from Germany's transmission system operators (ÜNB 2014). The starting point of the plan is the currently installed total net feed-in capacity available in Germany during the annual period when demand is at its peak.

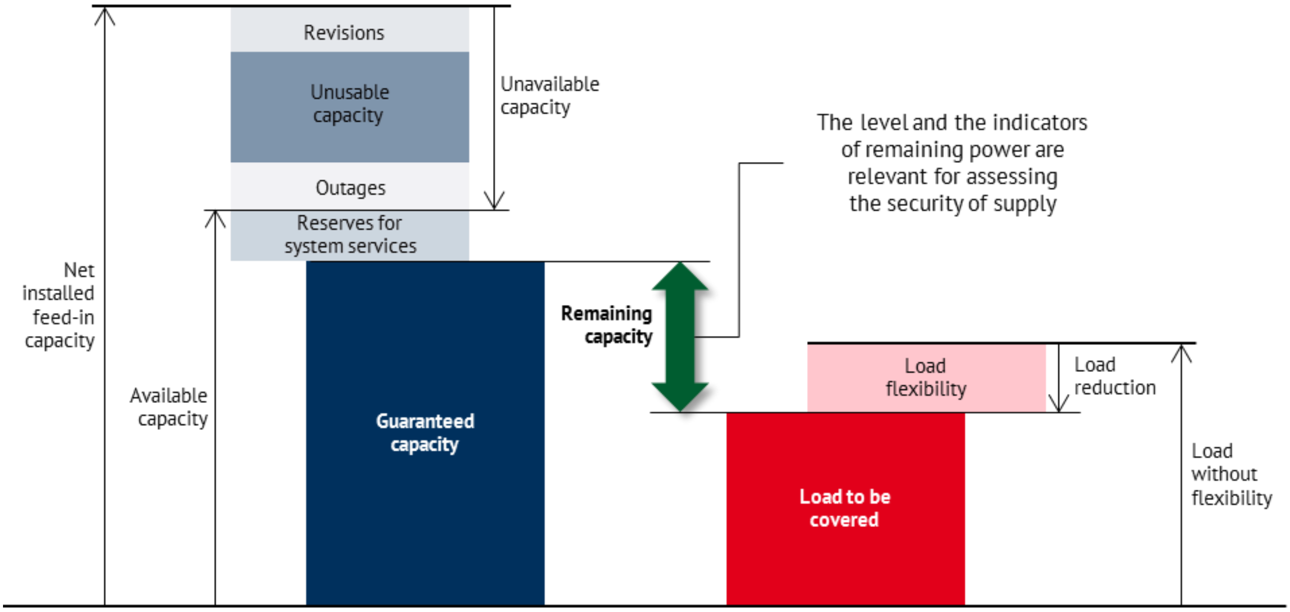

Figure 4: Transmission system operators' plan for calculating guaranteed capacity.

However, this installed capacity is not fully available at the time of peak demand for the year because inspections/revisions, outages, reserve capacity for system services and capacity that cannot be used due to weather conditions all reduce guaranteed capacity. With one exception, these performance-reducing factors are not predictable in the long run. Only inspections/revisions can be planned so that they do not occur during the annual period of peak load (not fully known in advance, but well assessable). Moreover, the annual peak load does not need to be fully covered; some demand for power is flexible and responds to high electricity prices or can be controlled directly by the grid operator. The difference between the remaining load to be covered and guaranteed capacity has long been an important factor in the planning of supply security.

The Green Paper on the Electricity Market (BMWi [German Ministry for Economic Affairs and Energy] 2014) shows a remaining capacity of about 10 GW and refers to the report on power balancing by Germany's transmission system operators (TSOs). Judging from this figure, Germany's nuclear phaseout is accompanied by high overcapacity. The Green Paper also points out that this is not unusual in Europe and indicates that the electricity markets relevant for Germany boast an overcapacity of altogether 60 GW. This volume is available to individual countries of course only to the extent of cross-border transfer capacities. In the medium term, the BMWi does not expect capacity to be scarce in a strongly interconnected European electricity market.

The impact of Germany's nuclear phaseout on remaining capacity is reviewed below. The starting point of the analysis is thereby the development of installed capacity in 2011 and 2015 according to Fraunhofer (2016) and future power plant capacity according to estimations in the current 2016 EU Reference Scenario of the European Commission (2016a). Figure 5 shows capacity development in comparison to Germany's annual peak load of 84 GW according to Germany's TSOs (ÜNB 2015).

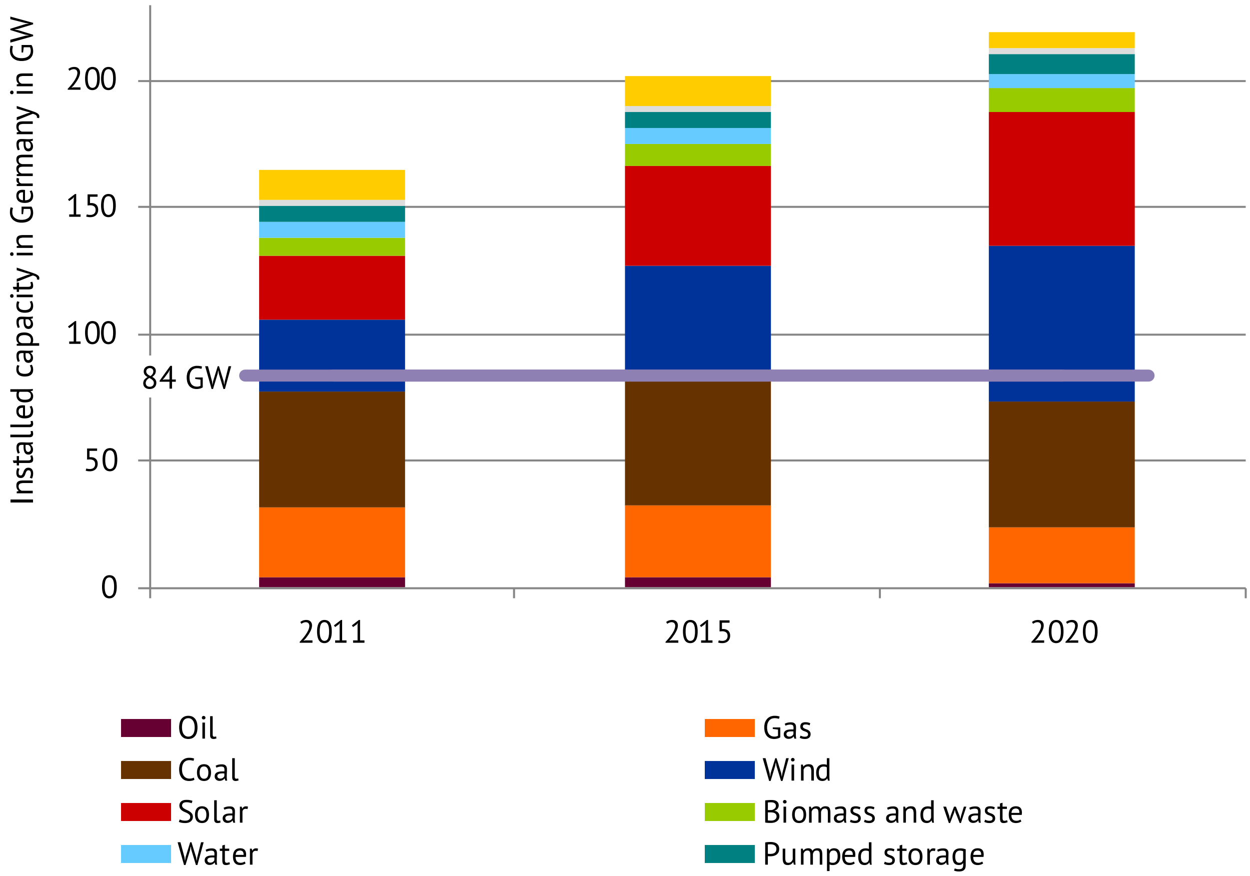

Figure 5: Installed capacity in Germany compared to annual peak load.

Wherever possible, the analysis has selected conservative assumptions to make sure that the security of supply is not overestimated. The estimations of guaranteed and available capacity are shown below in Table 1 together with the sources of information. A zero percent contribution towards supply security is shown for photovoltaics because Germany's annual peak load occurs after sundown on winter weekdays. Here it can be noted that the dynamic development of combining photovoltaics and household power storage will have an increasingly positive effect in future on the security of supply.

According to figures from the BMWi [German Ministry for Economic Affairs and Energy], wind power can guarantee 7 percent of installed capacity; in other words, it provides a regional balancing effect. On land or at sea, there is enough wind blowing during the period of annual peak load to guarantee 7 percent of electricity feed-in. The larger the area taken into account for wind power, the greater the contribution towards guaranteed capacity. The BMWi assumes that the figure goes up to 14 percent if all of Europe is taken into account.

Table 1: Estimations of the capacity available from different power-generating technologies.

Source of energy	Guaranteed availability in % of installed capacity	Source of information
Solar	0	TSO (2014)
Wind power	7	BMWi (2014)
Hydropower (run-of-river and storage power plants)	58	Own calculation
Biomass plants	64	Own calculation
Pumped-storage power plants	80	TSO (2014)
Fossil-fuel power plants	85	Prognos (2015)
Nuclear power plants	91.54	IAEA (2015)

For power plants in which output can be easily controlled, the share of installed capacity that is guaranteed is naturally much higher because their energy sources are mostly stored and can be purposefully supplied to the facility as needed. Depending on the technical design of the plant, a comparatively high share of guaranteed capacity can be achieved. On average, this share is 58 percent for run-of-river and storage hydropower plants, more than 64 percent and 80 percent respectively for biomass and pumped-storage power plants, and up to almost 92 percent for nuclear power plants.

Figure 6 shows guaranteed availability in comparison to actual installed capacity for each technology. Despite the nuclear phaseout, available power plant capacity expanded from 2011 to 2015. Compared to the annual peak load at a consistent level of 84 GW (according to data from TSOs in 2015), grid operators had enough capacity in reserve for system services in 2011 (6.4 GW) and 2015 (13.4 GW). According to the TSO power balance report, up to 5 GW should be available for this purpose; this is the sum of primary balancing or control reserve, positive secondary balancing or control reserve and minutes reserve. It is not expected that supply security will be facing any strain in this context during the years up to 2020.

The potential for flexibility identified in Energy Brainpool/Fraunhofer IWES (2015) would help to achieve consistently high security of supply more cheaply. Power plants needed only during the period of annual peak demand are economically inefficient due to their lower number of operating hours. Some rapidly realisable options for flexibility are included in Figure 6 and taken into consideration in flexible annual peak demand. Intelligent and flexible planning for the utilisation of existing biomass plants, taking into account the availability of other thermal power plants, decreases peak demand by about 1.7 GW; demand-side management (DSM) in industry decreases peak demand by 2 GW and in households by another 600 MW.[6] Potential short-term flexibility adds up to a decrease in demand of 4.4 GW. A cross-border approach towards supply security reduces costs even more; the flexible annual peak load indicated in Figure 6 below represents an assessment by the study's authors; however, there is still a need for further investigation.

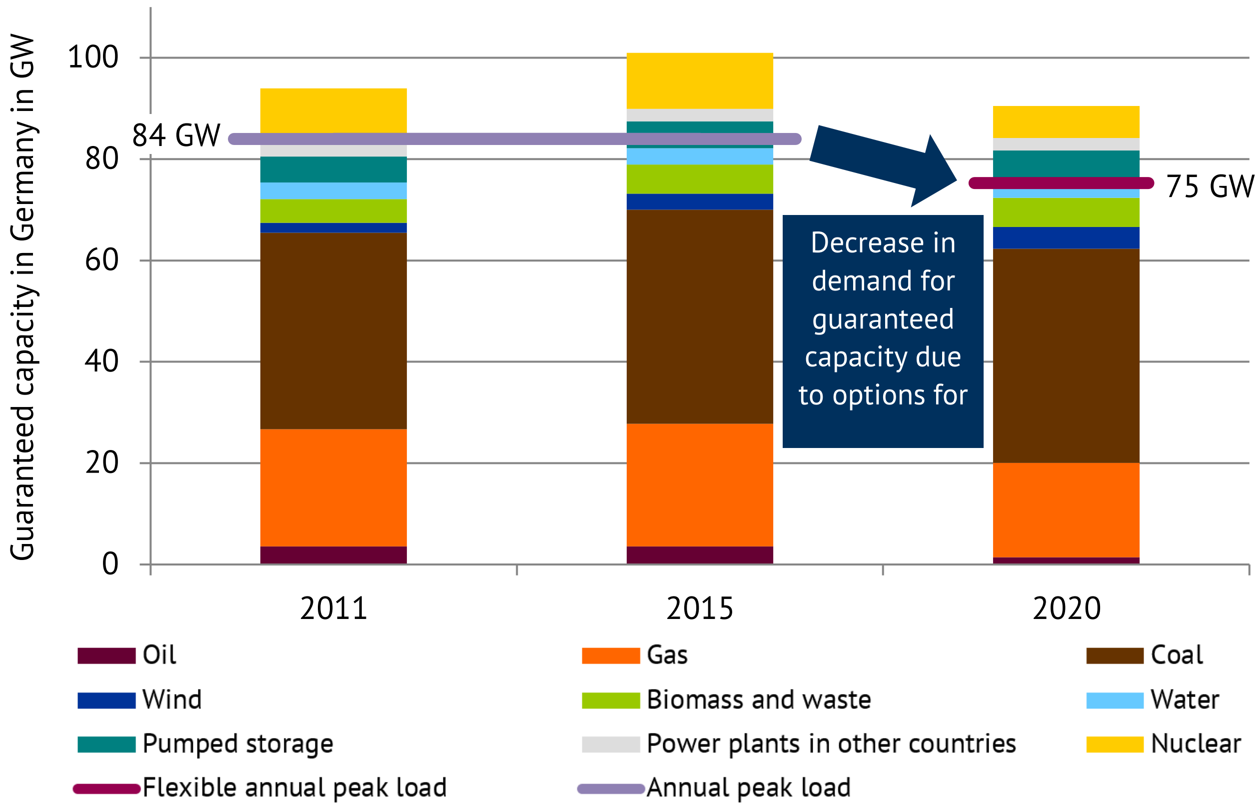

Figure 6: Guaranteed capacity in Germany compared to annual peak load with flexible load and power generation.

In subsequent years of the energy revolution, the expansion of renewable energies is expected to be based largely on wind and photovoltaic facilities. To then be able to continue ensuring a high level of supply security in an energy system based on renewables, it will be necessary to use options for flexibility (see Energy Brainpool/Fraunhofer IWES 2015). Options such as short-term storage (batteries) and long-term storage (power-to-gas) can contribute on the power generation side to increasing the security of supply. Flexibility on the demand side (DSM) will also take on particular importance. By applying DSM, annual peak demand can be reduced based on (operational) business considerations. To this end, further adjusting to the conditions of the electricity market will be needed; to a certain extent this is already being implemented through the Electricity Market Act (see Energy Brainpool / Fraunhofer IWES, 2015).

[6] In households, present demand can be flexible in the short term only to a limited degree, but there are good figures for the installation of decentralized home electricity storage units, a technology which will in principle also allow more short-term flexibility in future.

THE DEMAND FOR BALANCING POWER

Another approach for considering the security of supply in the period after 2011 is the need for and the use of balancing power. Balancing power (or control power) is always used when short-term adjustments in power feed-in are needed by the grid operator. This is regularly the case because the flow of electricity within a quarter of an hour is not balanced by the market but only by the transmission system operator (TSO). The grid operator must also intervene when there are errors in forecasting, when failures occur in power plants or parts of the grid, or when consumers do not use electricity as expected. Primary control reserve (PCR) compensates deviations in feed-in to the grid and offtake from the grid at very short notice, while secondary control reserve (SCR) and minutes reserve (MR) compensate in the medium term.

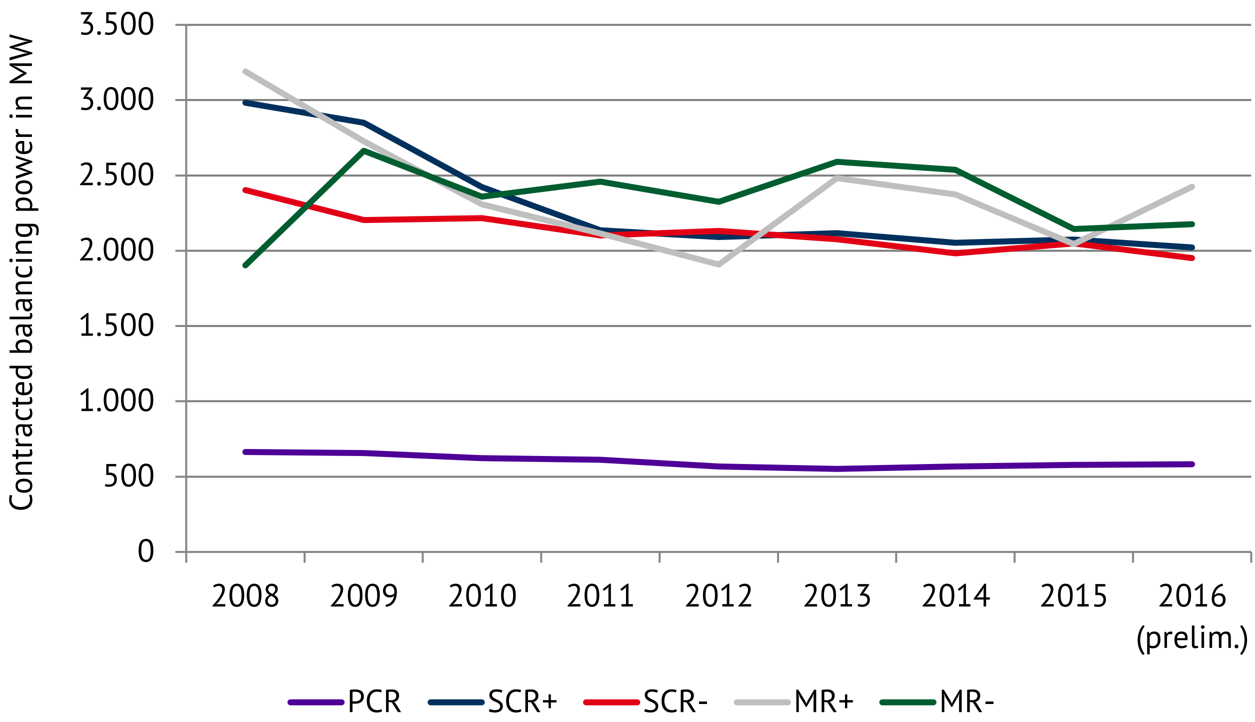

Figure 7: Average demand for balancing power in Germany and cooperating countries. (Source: 50Hertz, 2016)

Both the average demand for balancing power (Figure 7) and the average use of balancing power (Figure 8) have fallen in comparison with demand and use in 2011. Furthermore, as seen in Figure 8, the quantity of balancing power required in situations calling for comparatively high amounts of balancing power have declined. TSOs have therefore not needed to access high levels of contracted control power as frequently as before.

This evaluation of balancing power (also called control energy or control power) shows that during the period of the nuclear phaseout grid operators on average needed less control power to operate the grid with stability. Moreover, during the same period, the volume of control power needed by transmission system operators to balance the grid declined (see this development as indicated in quantiles in Figure 8).

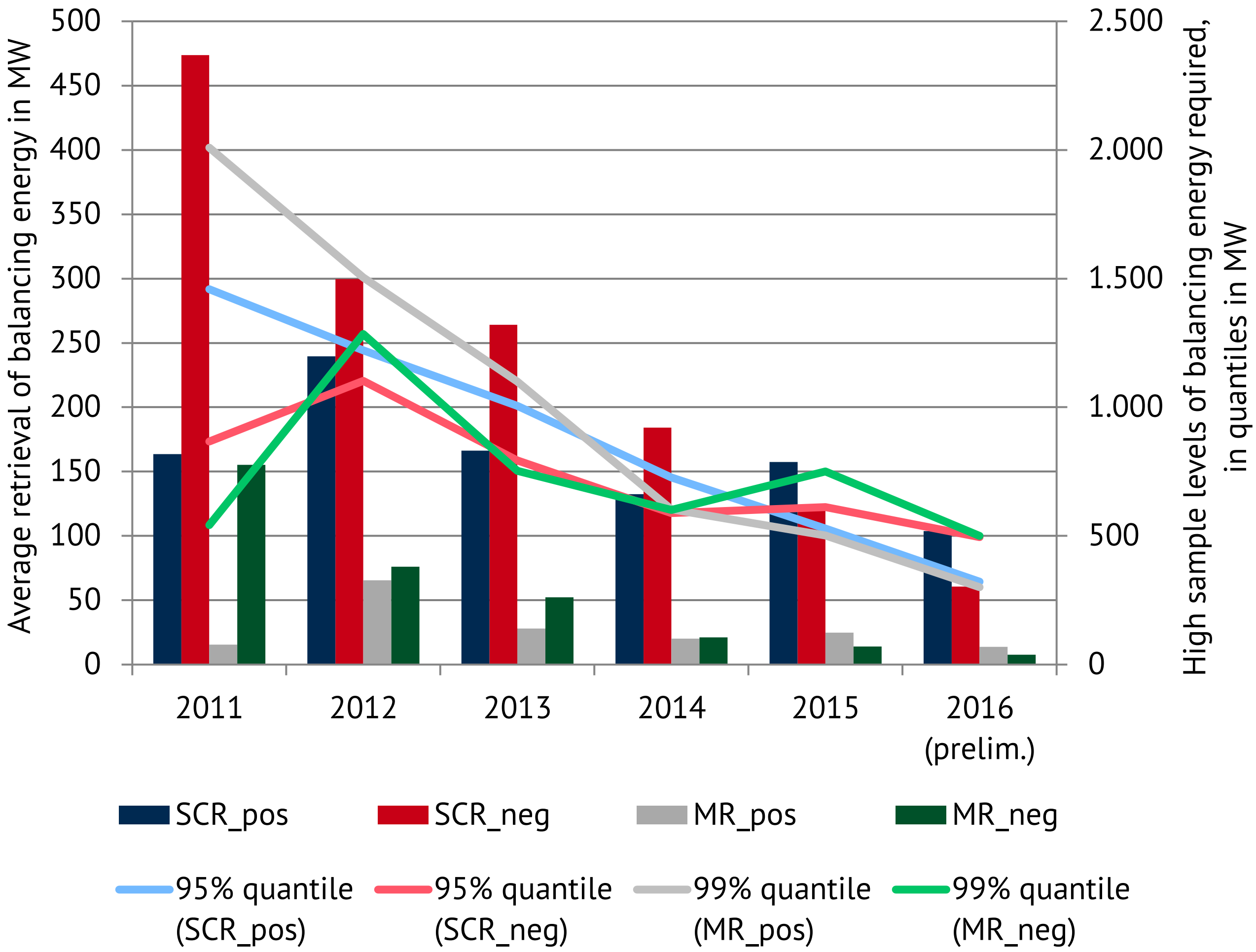

Figure 8: The average retrieval of balancing energy and a sample high level of balancing energy required in the respective year, expressed in quantiles/percentiles (95% quantile: the top 5 percent of the highest call-ups of control power in the respective year were above the shown value). (Source: 50Hertz, 2016)

Moreover, despite the uncertainty of meteorological forecasts, the expansion of intermittent renewable energies during this period has not led to higher demand altogether for balancing power. It is generally believed that the underlying reasons for this decline in demand for balancing power are the improved cooperation of grid operators at the national and European level as well as an intensification of short-term trade during this period of time.

CONCLUSION

This brief analysis has examined the impact of Germany's nuclear phaseout on the security of supply in the country. In the period of time from 2011 until now, nine nuclear power plant reactors with a total installed capacity of 9.7 GW, a figure representing more than 10 percent of the volume of Germany's peak demand for electricity, have been irrevocably shut down. At the same time, the share of renewable energies in electricity consumption has risen from 20.4 percent (2011) to an estimated 31.6 percent (2015). Three indicators of supply security,

- the System Average Interruption Duration Index (SAIDI),
- guaranteed capacity, and
- demand for balancing power,

show that in the same period, despite the nuclear phaseout and the growing proportion of renewable energies in the system, there is a consistently high if not increasing level of supply security. Even in extreme situations, such as the solar eclipse on 20 March 2015, when power generation from photovoltaics fluctuated (production gradients), which is normally expected only for significantly higher shares of renewable energy, the security of supply was ensured.[7]

The above indicators show that a high level of supply security has been maintained so far during the nuclear phaseout at the same time that power production from renewable energy sources has increased. However, to this end a number of other measures have been necessary, in particular the expansion, reinforcement and intelligent control (smart grid) of the electricity network regarding transmission and distribution, and the changing operational behaviour of power producers and power consumers that is illustrated in the strengthening of short-term electricity trading and the adjustment of electricity consumption to the available supply of renewable energies (demand-side management). Exactly how these measures have contributed in detail to ensuring supply security, and which specific share they have addressed, needs further investigation.

Further options for making the electricity market more flexible through the consistent introduction of demand-side management, short-term storage (batteries) and long-term storage (power-to-gas) play a key role in adjusting the electricity system to accommodate a high share of renewable energies and simultaneously maintain a high level of security of supply. Parallel to making the energy system more flexible, the grid, originally designed for large and centralised power plants, must be adapted to meet the challenges of an increasingly smaller and decentralized structure of renewable power production with changing geographical distribution.

If this transformation of the energy system is to be successful in a market economy and thereby utilise the synergies of a common European domestic market, regulatory frameworks at national and European levels must be correspondingly adapted. The roadmap for transforming the electricity market is described in the White Paper on "An electricity market for Germany's energy transition" (BMWi 2015a) and the transformation process has already begun with a reform of Germany's energy laws in the form of the Electricity Market Act and the Act on the Digitisation of the Energy Transition.

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[7] After the eclipse began, electricity generation from photovoltaics dropped by 11 GW within an hour. When the eclipse ended, power production rose again by 18 GW within one-and-a-half hours (Energy Brainpool, 2015).

At the European level, the Joint Declaration for Regional Cooperation on Security of Electricity Supply in the Framework of the Internal Energy Market was signed on 8 June 2015 by the so-called "12 electricity neighbours" (BMWi 2015b). The agreed goal of this declaration is the joint cooperation of these countries on making supply and demand flexible, both in grid expansion and the security of supply. In the course of the energy revolution, it is important to consistently continue with and further develop the measures which have already been initiated.

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ABOUT ENERGY BRAINPOOL

Energy Brainpool is the independent market specialist for the energy sector, with a focus on the electricity and energy trade in Europe. Our expertise includes **analysis**, forecasting and modelling of energy markets and prices, scientific and practice-oriented studies, **individual consulting** as well as **training** for the energy sector.

Energy Brainpool combines knowledge and competence with practical experience in the fields of controllable and intermittent energy sources.

Energy Brainpool's expertise and comprehensive services are mirrored in its customer portfolio which is made up of many renowned companies and clients: As a consultant, Energy Brainpool works out the yearly price-components of the EEG apportionment surcharge for the four large Transmission System Operators in Germany and conducts studies on topics such as the electricity market design for market participants as well as for different government departments and regulators. Energy Brainpool also consults the Federal Ministry for Economic Affairs and Energy (BMWi) about the further development of the electricity market. Energy Brainpool also trains and certifies traders for the European Energy Exchange (EEX). Energy Brainpool offers regular training courses for (inter-)national energy suppliers and service companies, banks, investors and energy traders.

OUR PHILOSOPHY

Neutrality, independence, reliability and a comprehensive understanding of the energy sector and energy markets – these are the basics for implementing optimal solutions to the challenges in a changing market. As a competent partner, we offer combined services to handle all issues of the energy trade under one roof. Our services are shaped by your needs and combine our expertise in the fields of analysis, consultancy and training for your future business success.

INDIVIDUAL PRODUCTS AND SERVICES

With our comprehensive service concept, we are able to support our customers in the fields of policy, finance, strategy and organisation. We accompany our customers throughout all phases of the solution process – from scientific analysis, individual consulting and development of the ideal strategy and required tools to practical realisation as well as staff and management training.

Analysis

Our fundamental energy market model Power2Sim models energy prices and scenarios until 2050. Our spot price forecast serves as a short-term forecast for trading and dispatching. Constant observation of the market as well as inside knowledge helps us to optimise our analysis models and project current trends.

Consulting

As market specialists we offer strategic and operative consulting for the energy sector.
Our strength lies in the areas of market transformation with increasing levels of renewables, in Germany’s energy transition, as well as in trading, portfolio and risk management. We enable our customers to adapt and to grow in this changing market environment.

Training

In individual training, seminars and workshops, we deliver our manifold knowledge of and insights into the energy sector. We offer in-house seminars, e-learning courses, practice-oriented simulation games for the energy trade as well as specialised events and conferences.

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