Optimal Level of Supply Security in the Power Sector with Growing Shares of Fluctuating Renewable Energy

By Aaron Praktiknjo and Lars Dittmar

Aaron Praktiknjo is with RWTH Aachen University, Institute for Future Energy Consumer Needs and Behavior (FCN), Mathieustr. 10, 52074 Aachen, Germany, E-Mail: aaron.praktiknjo@rwth-aachen.de, corresponding author. Lars Dittmar is with TU Berlin, Department of Energy Engineering, Chair of Energy Systems, Einsteinufer 25 (TA 8), 10587 Berlin, Germany, E-Mail: lars.dittmar@tu-berlin.de

In many countries a rapid expansion of intermittent renewable power generation has occurred in recent years. Simultaneously, conventional power plants such as nuclear generators are being phased-out of the energy system. Especially the German power system is characterized by these two developments.

In this context, appropriate methods for the assessment of the security of electricity supply are more important than ever. In general, there are deterministic and probabilistic methods to assess security of supply or generation adequacy respectively. In the past, the four German transmission system operators (TSOs) have relied on a deterministic approach. However, while there is a continuous debate about methodological details, it is widely acknowledged that probabilistic approaches are more appropriate that deterministic ones especially in light of the stochastic nature of intermittent renewables. We share this opinion and, therefore, revert to probabilistic methods.

While policy makers in Germany circumvent the question of appropriate level supply security by not defining it explicitly, we argue that rational policies must derive the level security from economic considerations. Ideally, investments in supply security should only be made if the resulting benefits outweigh the costs. With our research, we want to contribute to the economic assessment of security of supply and thereby provide a rational guideline on how to derive an economic efficient level of security.

SUPPLY SECURITY OF CONVENTIONAL GENERATORS

In order to assess the contribution of conventional plants to generation adequacy, we use the so-called methodology of recursive convolution. The basic idea behind it is that single production units are allowed to only be in two possible states: available and unavailable. With this, the state 'non-available' of a given plant occurs with a specific probability of (p) while the state 'available' occurs with the complementary probability of ($1 - p$). We differentiate unavailability in scheduled (maintenances) and unscheduled unavailability and formulate an econometric model to account for observed seasonalities, see figure 1.

Using the information of installed capacities and the probabilities of occurrences on availability and unavailability, the result of our recursive convolution will be a cumulated distribution function of the available generation capacity of the entire portfolio of conventional power plants.

CONTRIBUTION TO SUPPLY SECURITY OF RENEWABLE GENERATORS

The distribution of available capacity of renewable is rather continuous (ranging between 0 and 100 %) than discrete binary. We therefore use aggregate data of the feed-in from renewable power generators. We rely on hourly time series published by the German TSOs for the feed-in of wind and photovoltaic plants. The times series for wind ranges from 2006 to 2014, whereas the data for photovoltaic range from 2011 to 2014. In order to increase representativity of our time series we employ two supplementary approaches. First, we formulate a polynomial regression model of order 3 using weather data (e.g. wind speed) from over 60 stations as independent variables and the TSO time series for the period from 2006 to 2014 as dependent variable. The regression yields a high goodness of fit with exceeding 95 % when pitted against the actual data on feed-in from the TSOs from 2006-2014. Using this model, we extend our data on feed-in to a period of over 21 years

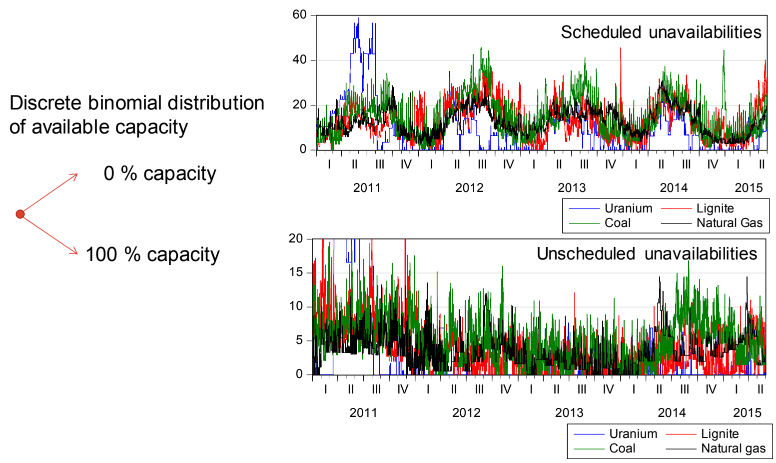


Figure 1. Unscheduled and scheduled unavailabilities of generators

(from 1994 to 2004), see figure 2. Second, we apply the so-called sliding window technique to increase representativeness of the data, including also feed-ins at times to proximity of the examination time.

Given the information presented above, we can express the available capacity of renewable generators in dependence of the probability of occurrence and time of the year. Therefore, we also receive a cumulated distribution function.

THE OPTIMAL LEVEL OF SUPPLY SECURITY

From an economic and welfare perspective, the optimal level of supply security is achieved if marginal cost for an increase in supply security is equal to marginal utility for an increase in supply security. Ideally, investments in supply security should only be made if the resulting benefits from an increase in supply security amounts at least to the investment outlay.

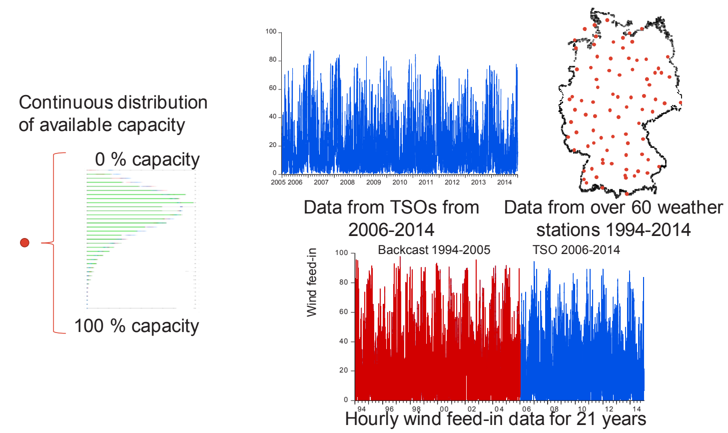


Figure 2. Availabilities of renewable generators

Supply security can be increased by installing additional generation capacities. As we know, the identification of the economically most viable option for the choice of generation technology depends among others on the annual full load hours of operation. In the case of Germany with its already relatively high level of supply security, the full load hours would be very small. Thus, the cheapest option would be to invest in gas turbines. The marginal cost of supply security would be almost equal to the capital cost of an additional gas turbine.

As for the utility of increased supply security, we can interpret it as the avoided cost of reliability issues. In the electricity business, these avoided costs correspond to the so-called value of lost load (VOLL). In a previous publication, we showed that the VOLL is dependent on the duration of an interruption in supply (VOLL increases significantly with shorter durations of interruption) and estimated it for Germany.

Given the data on marginal cost and marginal utility for an increase in supply security, it becomes possible to estimate the welfare optimal level of supply security.

RESULTS

We convolve cumulated the distribution functions of conventional and renewable generators using Monte Carlo simulation techniques to obtain a cumulated probability density function for our total generation portfolio for every hour of the year. Figure 3 shows the result for the hour of the German peak load in 2014 (79.1 GW on December 3, 2014 between 5 and 6 p.m.). Here, the probability of a deficit in supply compared to the demand for the hour of the peak load alone is lower than 10^{-12}.

After having calculated the secured capacity of the total portfolio of power plants, we evaluate the contribution of the different types of generators to total supply security. To do so, we estimate the so-called capacity credit. The capacity credit represents the contribution of a group of generators (at a predefined level of supply security) to the secured supply of our total portfolio and can be interpreted as a kind of performance indicator for our group of generators. Figure 4 schematically depicts the methodology for the calculation of the capacity credit and shows the result for the German peak load hour in 2014.

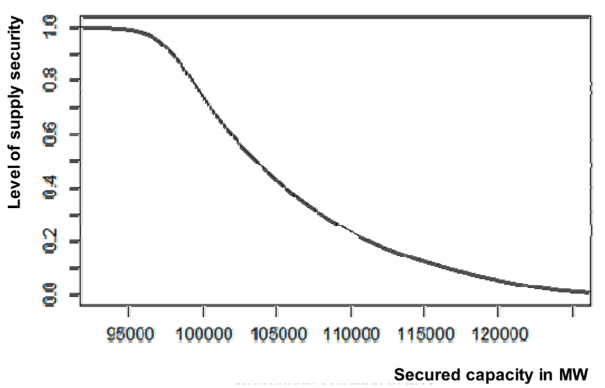


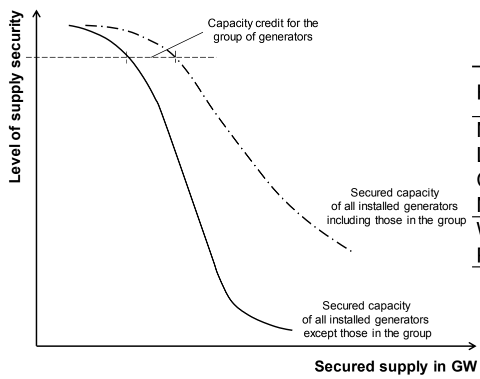
Figure 3. Cumulated probability density function for the entire generation portfolio

With our results, we can estimate that phasing-out nuclear power plants, *ceteris paribus*, obviously leads to a decrease in supply security. For the peak load hour alone, the level of supply security would drop from almost 100 % to a level of about 95 %.

Carrying out the assessment for the welfare optimal level of supply security, our results indicate that the optimal level of supply security over a year would be equal to about 99.99994 %. Translated to the level of supply security of the peak load hour, this would also amount to approximately 95 %.

DISCUSSION AND CONCLUSION

Our results indicate that the overall level of supply security in Germany in 2014 is extremely high with a probability of a deficit for the peak load hour alone of almost 0 % (below 10^{-12}). Our results confirm that the contribution of intermittent renewable capacities is much less than the contribution of conventional generation capacities. For the peak load hour, wind power contributes to supply security only by about 7.2 % of the installed capacity, while conventional capacities can contribute by about 95 % of the installed capacity. In other words, 1 GW of conventional power generation (e.g. nuclear power) has the same contribution to system adequacy as 13 to 14 GW of installed wind power. At the peak load, photovoltaic generation does not contribute to security of supply at all. This is caused by the fact that the peak load in Germany regularly occurs is in the evening hours of the winter.



Capacity credit for the time of the annual peak load

Fuel type	Capacity credit in percent
Nuclear	98.9
Lignite	94.9
Coal	94.7
Natural Gas	96.2
Wind	7.2
Photovoltaic	0.0

Figure 4. Calculating the capacity credit (at a level of 95 %)

From our analysis we can conclude that the phase-out of nuclear power will ultimately lead to a decrease in the total level of supply security (from 100 % to 95 % for the peak load hour) while the installation of new renewable generators alone will hardly compensate for it. However, we have shown that the theoretically optimal level of supply security is equal to 99.99994 % in a year, which is equal to approximately 95 % for the peak load hour. Therefore, from an economic perspective, the decrease in supply security resulting from the phase-out of nuclear power plants would still be at a tolerable level. With this, new investments to re-increase the level of national supply security would be unnecessary and a waste of funds. But in the end, it is the German society that will be the one to decide on the final level of supply security, economic welfare or not.

Bergen Overview (continued) (Social Events)

On Tuesday evening the City of Bergen gave a reception in the magnificent Håkonshallen, King Håkon's Hall, represented by the Mayor of Bergen, Marte Mjøs Persen. Håkonshallen is a large medieval stone hall, built from 1247 to 1261 and inaugurated for the wedding of a King Magnus Håkonsson in 1261, with 2000 guests attending. The Mayor gave a brief account of the history of the hall and then dwelt upon the importance of energy for the economic development of Bergen and the region around it and the role of Bergen as the "energy capital" of Norway.

Bergen Conference Wrap-Up

All in all, the conference seemed to work well and many positive comments and feedback were received from conference participants. The conference facilities at NHH functioned quite satisfactorily and NHH was most generous and supportive in hosting the conference. Much praise was also received for the quality of the food served during the conference and for the service.

Last but not least: A sincere word of thanks and appreciation to the conference sponsors for their financial support, which made it possible to organize a qualitatively better conference than otherwise.

The Bergen Conference Team--Their hard work was instrumental to the conference's success