Impact of Geographical Diversification of Wind Plants on Generation Adequacy – A German Case Study

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Overview

The German energy action plan stipulates a share of renewable energy sources (RES) of 40-45% in electricity for 2025. In 2015 RES provided already 32.6% of gross electricity consumption, of which wind power had a share of 44.9%. However, the intermittent nature of wind power production makes it an unreliable power source. Moreover, there are concerns about generation adequacy due to the decommissioning of conventional generation facilities in Germany. While usually generation adequacy is maintained by conventional units, such as fossil fuel, hydro or nuclear units, it is questioned if wind power can be an option for the improvement of the reliability performance. Recent studies address the dependency between wind power allocation and the variability in the output of wind turbines. On the basis of a German case study, we investigate to what extent a geographical diversification of wind farms can support system reliability. The findings indicate that depending on the objective function of the wind power allocation the need for conventional generation units to supply the residual electricity demand can be decreased by more than 1GW compared to the reference case.

Methods

The procedure implemented in this study can be divided into four major steps. (I.) First, on the basis of publicly available data on the actual land use the *available land potential* for wind turbines is determined. Thereby Germany is represented by 8712 nodes. (II.) Second, we compute *normalized wind speed time series* for each node using hourly wind speed data from the German numeric weather model COSMO-DE. The wind speed data is transformed to the power output of a wind turbine using an exponential approximation. (III.) Subsequently, based on the available land potential and normalized wind speed data for each node the *wind turbines are allocated* to the sites using an optimization approach. In order to analyse the impact of the geographical diversification of wind plants on generation adequacy we apply four different models. The reference case is based on an objective function reflecting the current allocation of wind farms in Germany. Driven by feed in tariffs wind farms have historically been built at sites with high wind yields. Accordingly, model 1 maximizes the yield of the wind infeed over all sites and the period concerned:

$$\sum_{t=1}^{T} \sum_{r} i_r w_{r,t} \rightarrow Max! \tag{1}$$

where i_r is the decision variable indicating how much of wind generation capacity will be allocated to site r. The available wind power production $w_{r,t}$ for every site r and time step t is obtained according to step (I.) and (II.). The sum over the installed wind generation capacity i_r should equal the predefined RES target I_T (e.g. 40GW), which is modelled by constraint (2):

$$\sum_{r} i_r = I_{target} \tag{2}$$

Moreover, it has to be taken into account that the deployment of wind turbines at each node is limited by the maximum potential i_r^{max} for site r:

$$0 \leq i_r \leq i_r^{max}, \forall r \tag{3}$$

Model 2 addresses the dependency between the wind power allocation and the variability in the output of wind turbines and minimizes the variance of the wind infeed for the considered period. Model 3 maximizes the minimum infeed of all deployed wind turbines, which is equivalent to the maximization of the capacity credit of wind generation. Model 4 minimizes the residual peak electricity demand, which is calculated as total system load minus wind infeed of all deployed wind turbines for each time step. For the models 2 to 4 the same side constraints (2) and (3) apply.

(IV.) Fourth, in order to investigate the impact of the considered models on generation adequacy a *probabilistic convolution approach* is applied. Thereby we consider the stochastic superposition of power demand imbalances, intermittent wind generation and unplanned generation outages. We compute the required conventional generation capacity CR to maintain security of supply using a two security levels: 3 hours in 1 years (typical of interconnected power systems) and 1 hour in 10 years (typical of isolated power systems). A detailed description of the convolution approach and the underlying assumptions can be found in [1].

Results

Considering one meteorological year (2013), one reference wind turbine and a wind expansion target of 40GW first simulations indicate that depending on the objective function the need for conventional generation units to supply the peak electricity demand can be decreased by more than 1GW compared to the reference case (wind yield → Max!). Model 3 and 4 aiming at increasing the capacity credit of wind generation, show the highest potential for the improvement of the reliability performance (see CR in *Table **1***). This is related to a more balanced distribution of installed wind generation capacity over Germany (see right part in *Figure **1***), but also a lower wind production for the considered period (roughly $-25\ TWh$).

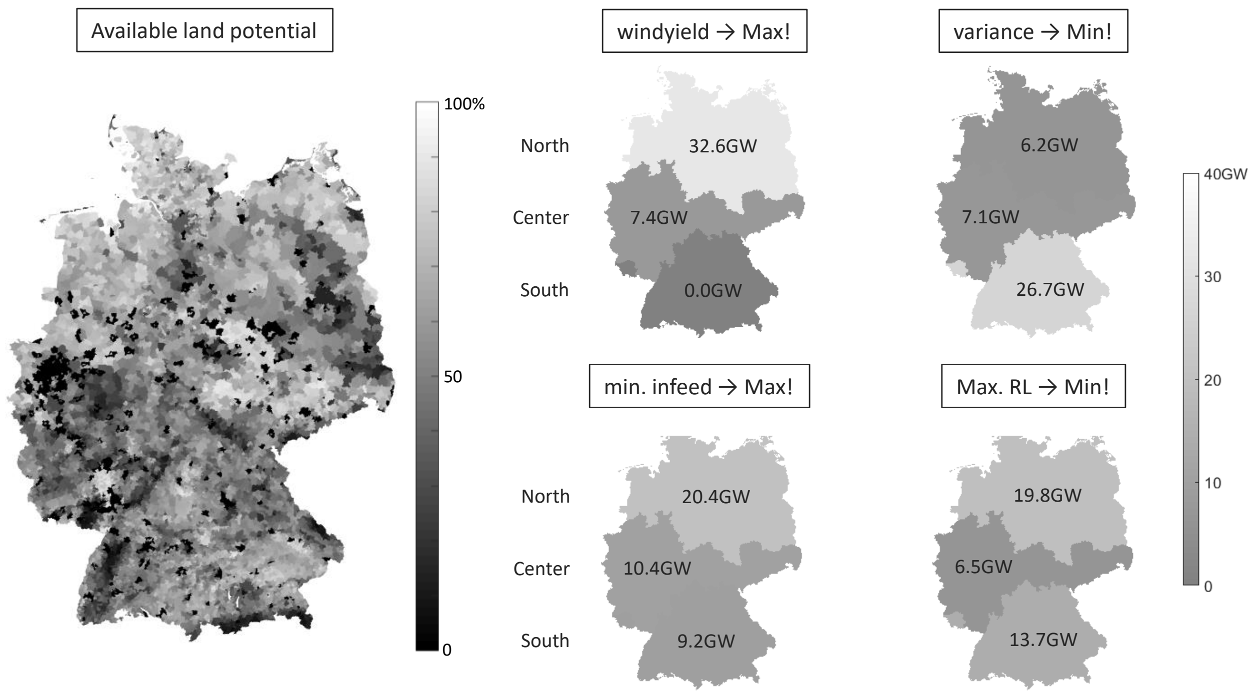

Figure 1: Available land potential in % per site and resulting wind allocation for Germany in GW per region

Table 1: Summary of main results with regard to generation adequacy (reference case: wind yield → Max!)

		Load	***Residual Load***			
	Case		wind yield → Max!	variance → Min!	min. infeed → Max!	max. RL → Min!
GWh	Sum	535,690	407,986	489,500	429,173	436,262
GW	Mean	61.15	46.57	55.88	48.99	49.80
	Maximum (Peak)	87.43	79.45	80.40 (+0.95)	79.42 (−0.03)	78.71 (−0.74)
	CR (3 hours in 1 year)	91.97	85.31	87.75 (+2.44)	85.18 (−0.13)	84.68 (−0.98)
	CR (1 hour in 10 years)	96.45	88.72	91.06 (+2.34)	88.58 (−0.14)	87.63 (−1.09)

Conclusions

In this contribution, we analyse the impact of geographical diversification on generation adequacy and determine the required conventional generation capacity to maintain security of supply using a probabilistic convolution approach. The model is applied to the German power system. First results reveal a potentially high contribution of wind infeed to generation adequacy, which could be further increased by a more balanced expansion of wind plants between northern and southern Germany. Further analyses will incorporate more meteorological years and reference wind turbines to improve the validity of the model.

References

[1] Bucksteeg/Spiecker/Weber (2017): Impact of Coordinated Capacity Mechanisms on the European Power Market. HEMF Working Paper No. 01/2017. Available at SSRN: https://ssrn.com/abstract=2896686