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Pelka, Sabine; De Vries, Laurens J.; Deissenroth, Marc

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The Impact of Weather and of Batteries on the Investment Risk for Backup Gas Power Plants in a Largely Renewable Energy System

Sabine Pelka

Fraunhofer Institute for Systems
and Innovation Research ISI
Karlsruhe, Germany
Sabine.Pelka@isi.fraunhofer.de

Dr. Laurens J. De Vries

Delft University of Technology
Delft, Netherlands
L.J.deVries@tudelft.nl

Dr. Marc Deissenroth
German Aerospace Center
Stuttgart, Germany
Marc.Deissenroth@dlr.de

Abstract— With an increasing wind and photovoltaic share, the German generation mix becomes more weather-dependent. Backup technologies can help to bridge scarcity moments. These rare moments with high prices are the main events for their cost recovery. However, the uncertain revenue flow combined with long payback periods leads to high investment risks and possibly insufficient investment.

A high level of needed backup capacity to cover the load does not necessarily go along with a high level of requested backup energy. Both indicators depend on the renewable output and the availability of alternative flexibility sources. We calculate them for two contrasting weather years and three levels of battery capacity by the agent-based-model AMIRIS. As a result, the demonstrated volatile backup energy request in combination with the same level of requested backup capacity for every scenario supports the idea of an alternative remuneration for the provision of capacity next to the energy-only-market.

Index Terms— Security of supply, weather, batteries, backup capacity, flexibility

1 INTRODUCTION

The increasing wind and photovoltaic share in the German generation mix reduces the CO₂ emissions but also creates more weather-dependent supply. In order to guarantee the security of supply, the volatile power output by the renewables asks for compensation by backup technologies such as gas turbines. They have to cope with a variety of scarcity moments, ranging from single peaks of uncovered load to longer scarcity periods. During winter times with little sun and wind but high demand, these scarcity incidents accumulate and represent the most critical moments for security of supply.

The need for backup technologies during these moments goes not along with certain cost recovery. As the last dispatched entity in the market, their main events for cost recovery in the energy-only-market are scarcity prices. Depending on factors, such as the weather conditions and the availability of competing short-term flexibility sources, it is

difficult to predict the level and frequency of scarcity prices. Uncertain investment conditions lead to investment restraints and harm the security of supply. Under different flexibility and weather conditions, our simulation evaluates the required backup capacity and energy and thereby gives insights to the research question “How do weather conditions and batteries impact the investment risk of backup gas power plants?”.

After an overview of the state of research (chapter 2), the choice of the model, the research design (chapter 3) and the scenario design (chapter 4) are described. The results are presented, tested in a sensitivity analysis and reflected in chapter 5, 6 and 7.

2 LITERATURE REVIEW

The news about two January weeks in 2017 with low renewable output triggered a couple of commissioned research projects about the impact of weather on security of supply in Germany.

In the course of the project about long-term energy scenarios for the German federal ministry about economic affairs and energy, a cost minimal optimization of the generation mix by 2050 results in a strong expansion of renewables without comprehensive investments in storage¹. Local and temporal concentrations of high residual load are managed with the help of cross border trade (Pfluger et al. 2017). The risk of similar weather patterns all over Europe is analyzed in a subreport, which is going to be published by the end of 2019 (Wissenschaftliche Dienste des Bundestags 2019).

On the basis of the same time series and installed capacity as Pfluger et al. 2017, the paper by Franke et al. 2018 compares weather years from 2008 until 2012 by using different indicators. The minimal output for wind energy compared to the installed capacity ranges from 18 percent for 2010 and 34 percent for 2008. Looking at the temporal and

¹ The weather year 2010 is used.

spatial dimension of wind energy shortages in Europe, the maximum of spatial expansion is given at 30 to 35 percent with a duration of 50 to 100 hours for most weather years (Franke et al. 2018). Longer durations are locally concentrated events with a spatial expansion of less than 5 percent (Franke et al. 2018). Those are less critical for the system-wide security of supply. Looking at the missing energy, the duration and expansion of wind energy, the weather year 2010 is pinpointed as the most critical one.

The German Meteorological Service analyses the weather years from 1995 to 2015 regarding the number of two consecutive days with less than ten percent renewable output compared to the installed capacity (Becker 2018). On the European scale, these moments occur only 0,2 times. Taking an isolated look on Germany, these moments occur 10 times more often. All in all, Franke et al. 2018; Becker 2018; Pfluger et al. 2017 stress the importance of cross border trade and investments into interconnectors for security of supply.

Respectively, in the studies by Gerhardt et al. 2018 and Huneke and Perez Linkenheil 2017, the most extreme weeks of scarcity and needed backup capacity to cover the residual load are identified for different weather years. Two weeks by the end of January for the weather year 2006 are highlighted by Huneke and Perez Linkenheil 2017 and for the weather year 2010 by Gerhardt et al. 2018. Only looking at the residual load for an energy system with 69 percent renewables, 72,8 GW needs to be covered by other sources than renewables in the worst case by Huneke and Perez Linkenheil 2017. Assuming a share of 95 percent renewables and a high degree of sectoral coupling, a maximum gap between demand and supply of 30 GW is demonstrated by Gerhardt et al. 2018.

Even though both evaluations have different research scopes and outcomes, both highlight the difficult investment conditions for backup technologies. Even under favorable conditions of sectoral coupling, Gerhardt et al. 2018 shows the need for additional investments in 30 GW backup capacity. According to Huneke and Perez Linkenheil 2017, the backup technologies only account for 0,1 to 3 percent of the traded energy per year.

This paper focuses on the discrepancy of the requested backup capacity and backup energy. The combination of these indicators for two extreme weather years and different levels of alternative short-term flexibility sources gives insights about the investment conditions of backup technologies.

3 METHODOLOGY

Two scarcity indicators are key for the investments into backup gas power plants. The peak of uncovered load indicates the capacity that needs to be installed. The requested backup energy gives insights about the cost recovery in the energy-only-market. Both scarcity indicators depend on the weather and the availability of alternative flexibility sources. Their impact is demonstrated in a set of simulations with two extreme contrary weather years and different levels of battery storage.

Besides the needed backup capacity in GW and the backup energy request in GWh, the duration of continuous scarcity periods² and their frequency substantiates the need for long-term flexibility providers instead of short-term flexibility sources, such as battery storage.

For the evaluation, two observation periods are chosen to present the scarcity indicators. First, the sequence of scarcity is presented for a short time horizon. As most publications indicate an accumulation of scarcity for two weeks, the two weeks with the most uncovered load are used. Second, a longer horizon of one year is used to identify the needed backup capacity and its energy request.

A key aspect of the research design is the selection of the simulation model. The used energy dispatch model needs to fulfill two requirements for the experiments. First, it needs to be a simulation that allows implementing a capacity gap. Second, it needs to contain elements that reflect the complex bidding strategy of storages. Both elements are well addressed by the agent-based-model AMIRIS, which is developed by the German Aerospace Center DLR (Reeg et al. 2013; Deissenroth et al. 2017). After a general description of the model, the arrangement of these two elements is explained.

The experiment is executed with the merit order model of AMIRIS. The generators place their bid based on their marginal cost. A markup for conventional power plants, which is developed by Klein 2018 is added as well. The demand and the renewable output are based on weather time series. The renewables receive a market premium and are marketed by direct marketers, which curtail the energy when the negative price cannot be compensated by the premium. A price cap of 1500 Euro per MWh is implemented. The generation mix is determined exogenously, which is described in the next chapter. The interaction of the actors is depicted in figure 1.

The storage is the only actor who is entitled to optimize its bidding to maximize its profit. It capitalizes on the price spread by charging during low prices and discharging during high prices. The upcoming prices and underlying dispatch without the storage are given to the storage to select the most attractive hours for its bidding. The level of future market information is determined by the parameter foresight. Thereby, the storage not only knows on which price to capitalize on but also how much energy it can bid without lowering the price. It needs to deliberate between selling less for a higher price or vice versa for its profit optimizing strategy. By this approach, the implementation of only one storage entity is possible so far.

No investment decisions are considered in the model. The exogenously determined generation portfolio allows to consider the aimed capacity gap of the research design. An cost optimized generation portfolio to cover the load by

² The duration of scarcity periods depends on the exogenously determined capacity gap. For scarcity periods with only a little hourly capacity shortage, a slight reduction of the capacity gap can change the picture of the continuous scarcity periods. This drawback is tested in the sensitivity analysis.

Cebulla 2017 is used as a basis, as it is based on the same time series. Its innovative storage technologies with an ambitious business case (e.g. power-to-x) are excluded to create the aimed capacity gap (see scenarios).

As this key influencing factor for scarcity is determined exogenously, it needs to be made explicit which results are only a consequence of the input parameters or a generalizable finding. The change of investment restraints in the sensitivity analysis helps to cope with this drawback in the research design.

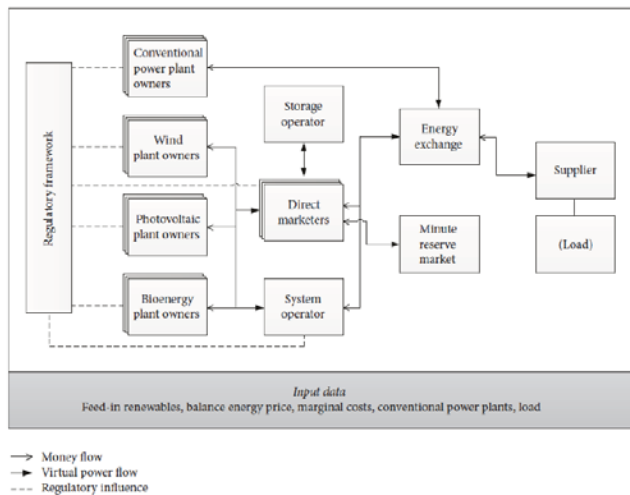


Figure 1: The interaction of actors in AMIRIS, source: Deissenroth et al. 2017

4 SCENARIOS

A set of three scenarios is created to test the impact on the scarcity indicators. One is used as a reference point, the other two to test the impact of the weather and the level of batteries, respectively.

The reference scenario describes the extreme case of a weather year with little renewables output. Pelka 2018 uses the same scarcity indicators for the selection of the weather as mentioned in the methodology. The weather year 2010 shows the most extreme forms of every scarcity indicator and is chosen for the reference scenario.

The used generation and storage portfolio by Cebulla 2017 is modified to fit the research questions. First, the renewable share is increased from 61 percent to the German target for 2040 of 65 percent by adding wind onshore capacity³. Second, 22 GW of other storage technologies than batteries are excluded for the aimed capacity gap.

In the reference scenario, the same capacity level for the battery storage (15 GW) is used like in (Cebulla 2017; Cebulla et al. 2017). For the configuration of the battery storage, a typical energy-to-power-ratio of five (Zapf 2017) and foresight of one day is selected.

³ A detailed derivation of the generation mix can be found at Pelka 2018.

To test the impact of weather, the same level of batteries but a weather year with a high level of renewable output is used. For the so-called mild weather year, the renewable output based on a weather time series of 2007 is used. In the analysis by Pelka 2018, it shows the lowest peak of residual load and the least scarcity periods compared to the other six weather years from 2006 to 2012.

To test the impact of the storage, a scenario with the extreme weather year and no storage is created. In the sensitivity analysis, the impact of the double amount of battery capacity (30 GW) is tested as well.

5 RESULTS

Three main findings are extracted from the experiments, which are explained in the following:

1. **Accumulation of scarcity:** For both weather years, the two weeks with the highest amount of uncovered load are at the same time the ones with the uncovered load peak and longest scarcity periods.
2. **A similar level of backup capacity needed but volatile energy request for both weather years:** Even though a similar level of backup capacity is needed to cover the load, the yearly backup energy request varies by 25 percent for both weather years.
3. **Enhancing the unfavorable investment conditions by short-term flexibility:** The 15 GW battery storage divides the backup energy request in half without mitigating the most critical moments of scarcity.

For every weather year, single moments occur in which a high residual load and limited flexibility lead to an extreme peak of the uncovered load. The simulation shows the almost identical level⁴ for the hourly peak for every scenario.

The severity of scarcity becomes explicit when one considers the uncovered load of the longest scarcity period of each simulated year (see figure 2). In the scenarios with the weather year 2010 and 15 GW installed battery storage, it lasts for almost three days and contains 0,25 percent of the yearly uncovered load. This period by mid-February includes the maximum peak of uncovered load and is surrounded by other long scarcity periods. In this sense, it is a stress test for the electricity system.

Apart from the same load peak, the intensity of the scarcity changes for the mild weather year 2007. Whereas 2007 shows more frequent but shorter periods of scarcity, the scarcity is concentrated in fewer but longer periods for 2010. The longest duration of scarcity asks for less than half of the energy of 2010. To cover the load, the same level of installed capacity is needed but under different income conditions for both weather years. The scenario with the weather year 2010 asks for 25 percent more additional energy to cover the load than the one with the mild weather year 2007 (see figure 2). The discrepancy of investment conditions for the same level of installed backup energy makes it explicit how difficult it is to design a well-tailored backup technology for these scarcity moments.

⁴ Difference of 2,3% (see figure 2)

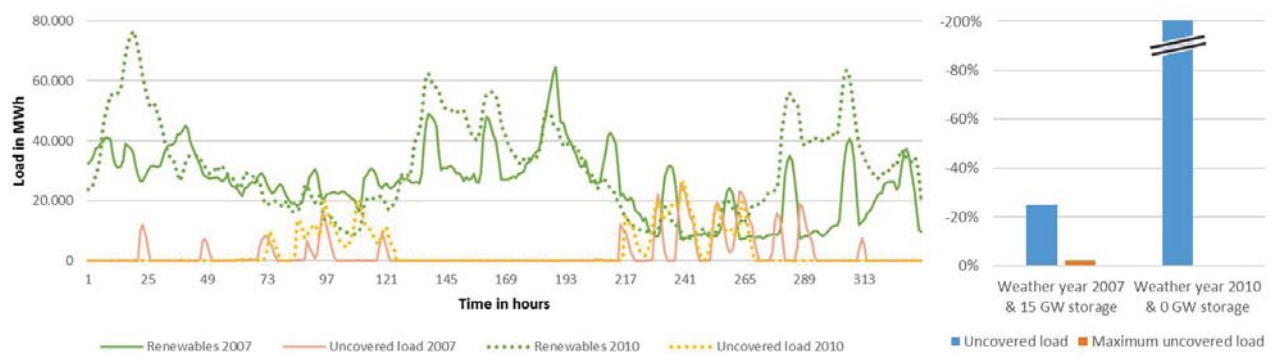


Figure 2: Renewable output & remaining load for the weather year 2007 & 2010 in the two most extreme scarcity weeks (left), change of annual uncovered load and maximum uncovered load compared to the reference scenario (weather year 2010 & 15 GW storage) (right) (both own representations)

The emergence of short-term flexibilities, such as battery storage, is a mixed blessing for the security of supply. On the one hand, the implementation of 15 GW battery storage divides the uncovered load per year in a half (see figure 2).

On the other hand, battery storage can hardly address situations of extreme scarcity alone. Only 10 percent of the uncovered load is reduced by battery storage during the longest scarcity period for 2010. The maximum uncovered load cannot be reduced at all by it (see figure 2).

The correlation of extreme scarcity peaks and long scarcity periods gives hardly any opportunity to charge during the extreme scarcity periods to the battery storage. For instance, more than one-third of the extreme peaks (in this case defined as 75 percent of the maximum peak and higher) is surrounded by a period of scarcity of 5 hours and longer⁵. It reduces the income basis for the backup technologies without substituting it in the critical moments.

6 SENSITIVITY ANALYSIS

The main impact factors of the scarcity are the availability of flexibility. In the experiments, those are represented by the battery storage and gas turbines as backup power plants. For the battery storage, the ability to react on scarcity depends on their knowledge of future prices, the foresight and their capacity. For the sensitivity analysis, the capacity is doubled to 30 GW and the foresight is extended from one day to one weeks and one month.

By doubling the battery capacity, the uncovered load per year is decreased by ca. 6 percent. This relatively small improvement is traced back to the rejection of the storage to reduce the scarcity price by covering all of the load and the limited foresight. The uncovered load and the development of prices in a constellation with competing storages is a subject of further research.

By extending the foresight to one week, the uncovered load per year is reduced by 20 percent. However, the positive effect of the longer foresight is bounded by the technical limitations of the battery storage (energy-to-power ratio). In the presented scenarios, no additional mitigation of the

⁵ The number of hours with uncovered load surrounded by the extreme peaks strongly depends on the capacity gap.

scarcity is achieved during the extreme scarcity periods in winter by a foresight of one week. Also, a longer foresight than one week cannot reduce the uncovered load per year any further.

The impact of minor investment restraints is addressed by adding 50 percent of the missing capacity in the form of gas turbines. The reduced missing capacity is directly translated into a reduction of the maximum scarcity peak by ca. 37 percent. This radical effect is also observed for the uncovered load. The uncovered load of the longest scarcity period accounts only for 12 percent of the reference scenario. For the entire year, it accounts only for 6 percent of the reference scenario. The amount of scarcity prices is four times lower.

All in all, a different modification of the battery storage shows a limited impact on the scarcity, whereas the change of the gas turbines capacity directly translates into a change of scarcity.

7 DISCUSSION

The impact of the weather and the availability of short-term storages on the investment risk of backup power plants is demonstrated with the agent-based model AMIRIS. By highlighting the mildest and most extreme weather year, the range of possible outcomes is provided, but no realistic view of the future weather developments and their yearly sequence. An in the deep analysis of long-term weather forecasts is subject to further research.

The contribution of short-term storages on security of supply is ambiguous. By covering the load during some scarcity moments, it reduced the investment basis of backup technologies. On the one hand, their limited energy-to-power ratio and capacity can hardly handle the coincidence of high scarcity peaks and longer scarcity periods. On the other hand, the storage needs volatile prices within one foresight period to charge and discharge. The storage becomes inactive for a long sequence of only high or low prices.

The monopolistic and almost omniscient⁶ representation of the battery storage enhances its limited contribution to security of supply. It optimizes its arbitrary strategy without the need

⁶ Knowing the future prices and dispatch constellation within a certain foresight

of considering the bids by other flexibility providers, which use an arbitrary strategy as well. Thereby, it maximizes its profit in some hours by restraining the stored energy to keep the market price on a high level.

In a competitive environment, it is unlikely that the independent bids by the different storage operators result in the exact amount of energy to use the high price without lowering them. As the price is likely to be lowered anyway, the storages create profit by selling their stored energy instead of holding it back. Therefore, scarcity moments tend to occur less frequently and with a lower magnitude in a competitive environment than in the simulation.

A well-coordinated ensemble of short-term flexibility in a competitive environment, which seize the potential of sectoral coupling and digitalization can help to mitigate their drawbacks. A more realistic representation of short-term flexibility is up to further research.

The potentials of cross-border trade as an alternative source to cover the load in times of scarcity is not explored. A fixed capacity for the cross-border trade is implemented in the simulation. The level of export depends on the interconnectors and the national availability of electricity. The latter depends also on the large-scale weather pattern for Europe, which is going to be addressed by the mentioned subreport of the long-term energy scenarios.

The most susceptible aspect of the research design is the self-determined level of investment restraints. More or less missing capacity would lead to a different level of scarcity. More secured capacity would directly lower the maximum peak of uncovered load. It reduces the remaining backup energy request and by adding the missing energy in some scarcity hours it lowers the duration of continuous scarcity periods.

Alternatively, an optimization model could determine an optimized generation mix according to an optimization objective (e.g. minimize system costs) and considering constraints. This approach neglects the investment decisions and possible investment restraints by actors on the micro level. Missing investments are a key underlying assumption of the research questions. Therefore, a model which enables the simulation of restrained investment and scarcity is selected. The impact of fewer investment restraints is tested as a sensitivity. Furthermore, an appropriate⁷ level of missing capacity for this simulation setup could have been determined by a sensitivity analysis before the simulation.

During moments with a high residual load in a perfect market, a combination of peakers⁸ and elastic demand would lead to an equilibrium. The consumers are either willing to pay the peakers for delivering energy during these moments or they are not consuming. In this simulation with mainly inelastic demand, the price settlement during scarcity

moments happens with the help of a price cap. The price cap and the mainly inelastic demand impede the described trade-off for setting the adequate price for cost recovery of the peakers.

The price settlement during scarcity moments is not only a bottleneck in this simulation but also in the ongoing discussion about the future market design. Under the given market prices, the demand⁹ mainly depicts an inelastic behavior. Revealing the hidden willingness-to-pay by exposing the demand to scarcity prices is a sensitive topic. Only a minor share of consumers developed a real price sensitivity so far and owns the knowledge and infrastructure to react according to it. Additionally, the German principle of secured basic supply for all customers does not intend lacking supply. Measures to trigger the price sensitivity under socially bearable conditions are subject to further research.

8 CONCLUSION

Facing an electricity market with mainly inelastic demand and a price cap, the evaluation gives insights about the investment risks depending on two extreme weather years and different levels of battery storage. The key indicator for cost recovery differs significantly between the two weather years and capacity levels of the battery storage. To be specific, the reduction of requested backup energy p.a. by 25 percent in case of a mild weather year and by 50 percent in case of adding 15 GW storage implies the unstable and insecure revenue flow for backup technologies.

Even though the investment conditions in the observation period of one year change for the different weather and flexibility constellations, the need for backup capacity is constantly high. The maximum uncovered load per hour stays almost at the same level for all scenarios. The battery storage is only marginally able to cover the load in time of longer scarcities. Consequently, the permanent need for a certain level of secured capacity does not go along with its cost recovery.

If the neoclassical approach of scarcity prices determined by the willingness-to-pay of the consumers is not considered feasible or desirable, alternative approaches to trigger investments in backup capacity can be discussed. The underlying idea of capacity mechanisms is to pay for the provision of secured capacity. Different forms are under discussion. For example, capacity subscriptions by Doorman 2005 contain a mechanism to involve the demand and detect their willingness-to-pay for security of supply. In general, the pivotal aspects of how to determine the level of capacity and its remuneration are subjects of further research.

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⁷ Testing how the cost recovery develops for different levels of installed secured capacity and stopping at a critical point for investment

⁸ Power plants with low fixed cost and high marginal cost - so far called backup power plants

⁹ Or retailing companies on behalf of the consumers, which translate the electricity prices into a fixed tariff most of the time for house holds

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