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Through the valley: The impact of PV penetration levels on price volatility and resulting revenues for storage plants

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ABSTRACT

This study analyzes the effect of electricity generation from photovoltaic on electricity prices and revenues for storage plants. Dispatch models are applied to derive hourly prices for the market region of Austria and Germany for increasing installed capacities of photovoltaic. These prices are used to calculate potential revenues for storage systems. Results show that the effect of increased feed in from photovoltaic depends on the penetration level. For low shares of photovoltaic in total electricity generation decreasing revenues and price variances are observed because of high correlations between demand peaks and solar radiation. The minimum of revenues for storage plants is reached at around 5% PV penetration level. For higher shares revenues start to increase significantly and are expected to be higher than initial revenues for penetration levels >10%.

Considering current shares of photovoltaic in Germany and Austria (year 2016) it is estimated that the effect of photovoltaic on price variance is around the observed minimum and price spreads can be expected to rise again with higher PV penetration.

With respect to investment incentives results show that although storage options can support the integration of high shares of intermittent renewables, short term needs and consequently electricity price signals might be low.

1. Introduction

In the literature and public debate it is widely assumed that increasing shares of wind and photovoltaic in electricity generation will increase price fluctuations and therefore stimulate investments for storage plants and other flexibility options like demand response measures. It is argued that variable renewables (VR) will lead to higher variance in demand for electricity generation from conventional power plants whose marginal production costs are typically setting the price for electricity in liberalized markets. It is also often argued that increasing feed-in of VRs calls for more electrical storage capacity and other flexibility options and that resulting price variance would provide incentives to invest in those technologies. Also the latest Impact assessment accompanying the document for a “Proposal for a Directive of the European Parliament and the Council on the electricity market”[1] highlights the importance of storage for the integration of renewables and expects a significant increase in storage capacity in the coming years. While the literature generally agrees that additional storage capacity is a cornerstone for the integration of high shares of VR in electricity supply systems, the short term effects for low to medium shares of VR in the system are less clear.

Some researchers argue that the effect of renewables on price volatility, which is an indicator for the economic value of storage plants depends on the penetration level of VR. Findings from some studies also indicate that feed-in from VR could even lead to decreasing price volatility. This would imply that incentives to invest in storage plants might be low as well and the expected uptake in storage investments might not materialize in the near future.

In this paper we contribute to the literature on the role of storage and intermittent renewables with a focus on the influence of feed-in from PV on price variance and resulting storage revenues. We highlight the importance of considering penetration levels of VRs in deriving conclusions on the profitability of storage and other flexibility options for increasing shares of renewables in the system. In the remainder of this section we give a short overview of the

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[1] https://ec.europa.eu/energy/sites/ener/files/documents/mdi_impact_assessment_main_report_for_publication.pdf.

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literature and define the research question and scope of this study.

Zucker et al. [33] provide an extensive literature review on the assessment of storage value in electricity markets including an overview of modelling approaches. The literature does not fully agree on the future role of storage. While some studies conclude that additional storage capacity will be crucial to integrate high shares of renewables (e.g. Refs [1,25] other studies conclude that storage needs are moderate and stress that storage competes with other flexibility options in the electricity system. (e.g. grid expansion or demand response – see Brouwer et al. [4].

In a study on the Italian electricity market Spisto and Hrelja [24] analyze the value of storage finding negative NPVs for investments in pump-hydro storage plants. Also the social value of storage including environmental effects is discussed arguing that price signals do not necessarily reflect social costs and the goal of emission reductions. Tuohy and O'Malley [26] estimate storage needs for high wind penetration in Ireland. It is argued that capital costs of additional storage plants are only covered in scenarios with very high wind shares >50% of total generation in Ireland. Krajačić et al. [13] and Zafirakis et al. [31] also indicate limited revenues for storage systems and discuss support mechanisms to increase incentives in storage investments.

Additionally to studies on storage profitability or storage needs also the literature on electricity prices contributes to knowledge on the relationship between VR and storage as the exploitation of price volatilities is the main source of income for storage plants. As shown by numerous researchers the feed-in of VRs with typically very low marginal costs leads to lower electricity prices in liberalized markets commonly known as the merit order effect (e.g. Refs. [6,8,18,20,23,27,28,30]). The direction of the merit order effect is clear, backed by theoretical explanations, and independent of the penetration of VRs. In other words, if resources with very low marginal costs are introduced to electricity markets, average spot market prices will decrease independent of the amount of VRs that are introduced to the system.[2] Lower average prices however do not allow for drawing conclusions on price variance, which is the focus of this study.

Besides abundant literature on price volatility in electricity markets using all kinds of econometric approaches (e.g. Refs. [5,10,21]), several studies focus on the specific impact of renewables on price volatility. Some researchers conclude that price variance increases with increasing shares of VR. Green and Vasilakos [11] conducted a study on the effect of wind penetration in UK for the year 2020 and find that prices are expected to be more volatile than at present. Studies by Brancucci Martinez-Anido et al. [3], and Baldick (2012) [15], on wind power in New England and Texas respectively also conclude that price volatility increases with increasing wind penetration. Milstein and Tishler [14], expect price spikes to occur more frequently with increasing shares of PV in the electricity system of California.

On the other hand Klinge Jacobsen and Zvingilaite [12], show that while price variance increases with increasing wind shares in Denmark, peak prices are observed less frequently. Tveten et al. [27], study price developments of the German electricity market from 2009 to 2011. They suggest that electricity feed-in from solar power led to decreases of average daily price maxima of 13% and reduction of price variations of 23%. We conclude that while it is clear that increasing shares of VRs lead to lower prices on average the literature does not fully agree on the direction of impacts of increasing VR on price volatility.

A recent study by Wozabal et al. [29], shows that the effect also depends on the installed capacity of intermittent resources. It is argued that small to medium additional quantities of VR can lead to lower price volatilities while larger amounts increase price variances which can be explained by shifts in the residual demand. This study builds on the findings from Wozabal et al. [29], and Tveten et al. [27], and focuses on the impact of PV penetration on prices. Our study contributes to the literature by further analyzing the effects shown in those studies. We test whether increased feed-in from PV leads to lower prices variance due to peak shaving for lower penetration levels and try to identify a tipping point for a PV penetration level at which price variance might start to rise again. As a measure for price variance we use potential revenues of storage plants for which price variance is the main source of revenues (e.g. see Ref. [16]). The main advantages of using storage revenues as indicators are that both seasonal and daily price variances can be included in one indicator and that modelling results allow for conclusions on the need for additional storage capacity or other flexibility options and incentives to invest in those technologies. The results of this study therefore also contribute to the debate on the relationship between increasing shares of PV and storage needs or profitability as discussed in Refs., [2,4,7,9,32], and allows for estimations on potential revenue developments depending on PV penetration rates.

There are several approaches to estimate the economic value of storage units (e.g. see Ref. [19]). In this study we use a fundamental market model of the Austrian and German electricity system to derive hourly electricity prices for various levels of PV penetration. We focus on PV as a source for price volatility. Other relevant input parameters defining price volatility are neglected to only show the effect of PV for various penetration levels. However we performed sensitivity analyses on those parameters revealing that the main conclusions drawn from modelling results are robust. Although there are certain limitations which we try to make clear in Section 2 we are confident that the approach allows for identifying mid to long term effects of PV integration on price volatilities in liberalized electricity markets similar to Austria and Germany and corresponding effects on the profitability of storage plants.

In summary the following main research question is addressed in this paper:

- What is the effect of additional installed PV capacity on price volatility and resulting revenues of storage plants or potential benefits of other flexibility options?

The contributions to the literature from this paper can be summarized as follows:

- We confirm the hypothesis stated in the paper by Wozabal et al. [29], that the effect of renewables on electricity price volatility depends on the penetration level of renewables with a numerical example for Austria and Germany.
- The paper deepens the knowledge of the effects of high shares of PV on electricity prices and shows that econometric models assuming a linear relationship between PV feed-in and price variance or models that only rely on data for low PV penetration levels can result in misleading conclusions with respect to the long term effects of PV on price variances.
- Implications for policy making and support schemes for PV in combination with storage units are derived.

The remainder of this paper is structured as follows. In Section 2 the methodology, models, and data will be explained. In Section 3

[2] There can be a theoretical case in which this does not hold. If, for example additional ramping and start-up costs of conventional power plants, resulting from fluctuations in residual demand offset reductions in fuel use of conventional plants, average prices could also increase if VRs are introduced. However at present this is not the case and numerous empirical studies show the price decreasing effect of feed in from VRs.