Energy Economics 62 (2017) 270–282

Contents lists available at ScienceDirect

Energy Economics

journal homepage: www.elsevier.com/locate/eneco

Does renewable energy generation decrease the volatility of electricity prices? An analysis of Denmark and Germany

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ARTICLE INFO

Article history:
Received 20 April 2016
Received in revised form 6 December 2016
Accepted 30 December 2016
Available online 11 January 2017

JEL classification:
C22
Q41
Q42

Keywords:
Electricity price volatility
Time-series model
Wind power
Solar power
Nord Pool
EEX

ABSTRACT

Although variable renewable energy (VRE) technologies with zero marginal costs decrease electricity prices, the literature is inconclusive about how the resulting shift in the supply curves impacts price volatility. Because the flexibility to respond to high peak and low off-peak prices is crucial for demand-response applications and may compensate for the losses of conventional generators caused by lower average prices, there is a need to understand how the penetration of VRE affects volatility. In this paper, we build distributed lag models with Danish and German data to estimate the impact of VRE generation on electricity price volatility. We find that in Denmark wind power decreases the daily volatility of prices by flattening the hourly price profile, but in Germany it increases the volatility because it has a stronger impact on off-peak prices. Our analysis suggests that access to flexible generation capacity and wind power generation patterns contribute to these differing impacts. Meanwhile, solar power decreases price volatility in Germany. By contrast, the weekly volatility of prices increases in both areas due to the intermittency of VRE. Thus, policy measures for facilitating the integration of VRE should be tailored to such region-specific patterns.

1. Introduction

The adoption of variable renewable energy (VRE) technologies is having profound consequences for the electric power industry. For example, buttressed by subsidies and priority grid access, solar and wind power generation in Germany comprised 25% of national electricity output in 2013 and facilitated a 30% reduction in CO_2 emissions relative to 1990 levels (von Hirschhausen, 2014). Likewise, neighbouring Denmark has adopted VRE-friendly policies enabling it to meet nearly 40% of its electricity needs through wind (Energinet.dk, 2015). However, similar shares of VRE generation in different electricity markets have resulted in contrasting effects on daily price volatility, which will affect the profitability of conventional power plants. Indeed, via a supply-function equilibrium model, Green and Vasilakos (2010) demonstrate that the incorporation of intermittent renewable resources can increase price volatility in the British electricity industry. Such a change in market will likely lead to an optimal generation mix using more gas-fired plants in the long run (Green and Vasilakos, 2011). Hence, understanding how VRE generation affects price volatility and uncovering the drivers of these effects is important for both power companies and regulators dealing with a transition to a more sustainable energy system.

While fundamental models are often used to examine policy implications, e.g., in terms of transmission expansion to accommodate increased VRE capacity (Egerer et al., 2013), such models need to be sufficiently detailed to capture the subtle changes that we seek to detect here. In particular, building and calibrating large-scale fundamental models with interconnected regions is often confounded by the complexities of deregulated electricity industries and the associated data requirements at the plant level, for example. By contrast, since the electricity industry is one of the few infrastructure industries with liquid markets and publicly available data on prices as well as cross-border transmission flows, we exploit this feature in taking an empirical approach to understand the effects of VRE generation on price volatility in Danish and German electricity markets.

Our methodology is largely based on Mauritzen (2010) who represents the volatility of prices via a seasonal autoregressive

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http://dx.doi.org/10.1016/j.eneco.2016.12.019
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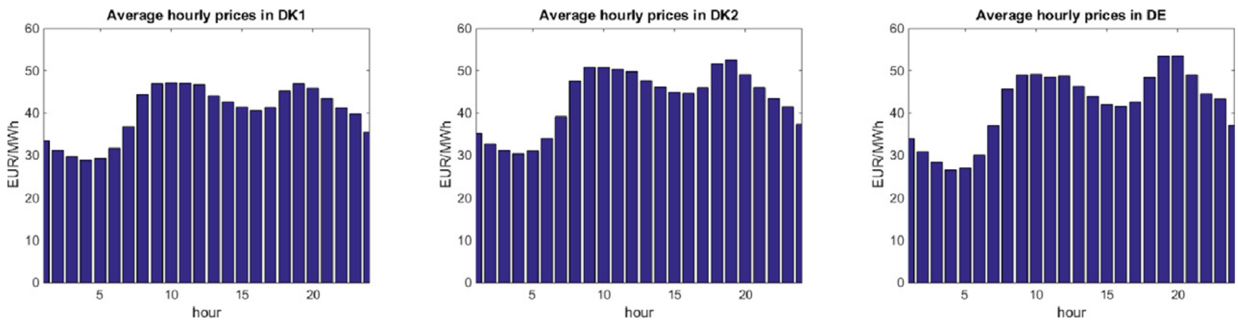


(a) DK1. (b) DK2. (c) DE.

Fig. 1. Average hourly electricity prices for DK1, DK2, and DE from 2010 to 2014.

moving average (SARMA) model in which wind power production is an exogenous variable. This methodology yields results that are straightforward to interpret and makes it possible to develop forecasts for electricity price volatility based on the data from previous days and information on regular consumption patterns. His conclusion is that Danish wind power decreases the daily volatility of the area prices in Denmark. On the contrary, Ketterer (2014) uses a generalised autoregressive conditional heteroscedasticity (GARCH) model and finds that German wind power increases the daily volatility of German electricity prices. Explaining these results using data from the two markets and distilling their implications for electricity markets in general is the objective of this paper.

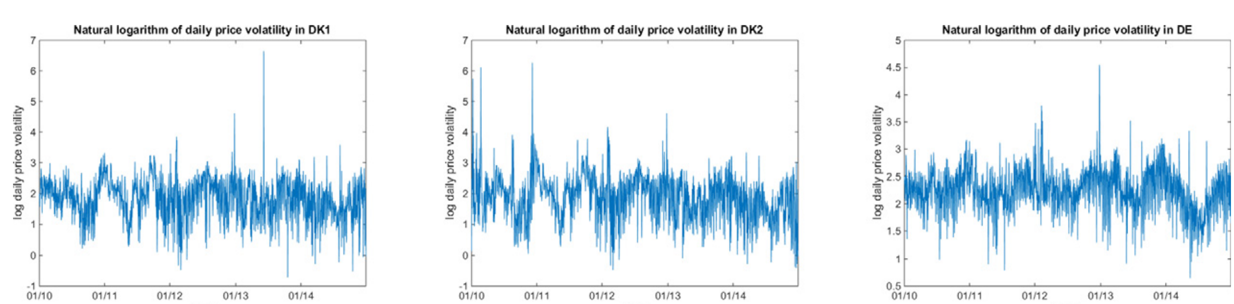
We proceed by first confirming the differing impacts of wind power on price volatility in these two markets and then explaining them by dividing the dataset into peak and off-peak hours with separate regressions for each subset of hours. This allows us to analyse changes in volatility by relating them to supply-curve elasticities and to the patterns of wind and solar power production as well as cross-border exchanges. Partitioning the dataset reveals that wind power output decreases daily price volatility in Denmark because wind speeds are roughly evenly distributed throughout the day. Relative to its average electricity demand, Denmark has high transmission capacity to the Nordic countries with large hydropower reservoirs, which may also explain Denmark's reduction in daily price volatility as both peak and off-peak hour prices are estimated to decrease nearly equally due to wind power generation. In Germany, however, there is an increase in price volatility because of greater wind power output during off-peak hours. Moreover, Germany's cross-border transmission lines are smaller relative to its average electricity demand, and it has limited access to flexible hydro generation. As a consequence, prices diverge as the price-decreasing impact of wind power is amplified during off-peak hours. Over a weekly time horizon, the level and the standard deviation of total VRE generation are found to increase the weekly volatility of electricity prices in both countries.

For producers and consumers alike, our empirical analysis not only corroborates earlier findings but also explains them by proposing plausible drivers. The implication of our results is that the allocation of generation and demand is becoming more important as average power prices decrease, but the achievable profit on different days varies significantly. To prevent intermittent renewable generation from threatening the stability of the power system, investments in flexible generation, extensions to the transmission network, integration of adjacent markets, and demand response will be required in the future. Moreover, additional trading opportunities by both producers and large consumers in intraday and balancing markets may be desirable (Mauritzen, 2015).

This paper is organised as follows. In Section 2, we review the literature on the impacts of VRE on Danish and German electricity markets, in particular. In Section 3, we present our model and analyse the time-series data. Section 4 presents the results for the effects of VRE generation on daily and weekly volatility. Finally, in Section 5, we provide conclusions and discuss directions for future research. Details on model selection and robustness checks are provided in the Appendix.

2. Literature review

The adoption of wind and solar generation technologies worldwide has necessitated a need to assess both the availability of resources (Yip et al., 2016) and their impact on electricity markets (González-Aparicio and Zucker, 2015). Many studies have investigated the effect of wind power production on price levels and



(a) DK1. (b) DK2. (c) DE.

Fig. 2. The natural logarithm of daily price volatility of DK1, DK2, and DE prices from 2010 to 2014.