ARTICLE IN PRESS

Energy Policy xx (xxxx) xxxx–xxxx

Contents lists available at ScienceDirect

Energy Policy

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

Electricity prices, large-scale renewable integration, and policy implications

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ARTICLE INFO

JEL classification:
C22
Q41
Q42

Keywords:
Intermittency
Large-scale integration
Merit-order effect
Volatility
GARCH-in-Mean model

ABSTRACT

This paper investigates the effects of intermittent solar and wind power generation on electricity price formation in Germany. We use daily data from 2010 to 2015, a period with profound modifications in the German electricity market, the most notable being the rapid integration of photovoltaic and wind power sources, as well as the phasing out of nuclear energy. In the context of a GARCH-in-Mean model, we show that both solar and wind power Granger cause electricity prices, that solar power generation reduces the volatility of electricity prices by scaling down the use of peak-load power plants, and that wind power generation increases the volatility of electricity prices by challenging electricity market flexibility.

1. Introduction

Electricity markets are gaining increasing importance on the global energy scene. Through adjustments in their market design, electricity markets endeavour to adapt to new challenges and integrate renewable energy sources into the power generation mix. Renewables pledge to mitigate climate change and diversify the energy mix, increase the security of energy supply, and decouple economic growth from increasing energy demand. However, the use of renewables has profound effects on the power systems with which they are integrated, and challenge the economics and operation of the electricity markets through their intermittent nature. See, for example, Pérez-Arriaga and Batlle (2012). It is subject to market design whether intermittent power volatility, caused by nature, will penetrate into the power system and pass-through to electricity prices.

Electricity prices reflect the physical peculiarities and economics of the power system as these are captured by supply and demand forces. On the one hand, there is the instantaneous nature of electricity and transmission constraints, and on the other the highly inelastic short-term demand (Sensfuss et al., 2008) and limited economic possibilities of large-scale storage rendering the behavior of electricity prices special and dynamic. Pricing methods that work in the case of financial assets often break down when applied to electricity markets, because the latter are driven by multiple factors and exhibit different underlying data generating processes. Deregulation of electricity markets, which already counts for more than two decades, has provoked fundamental reforms within electricity industries, by introducing increased competition and driving electricity prices to phases of relative tranquility followed by periods of high volatility. In this already challenging power system, intermittent renewables influence electricity prices according to the so-called 'merit-order principle,' which has its origins in the standard microeconomic concept of perfect competition. In line with this, the price of electricity should be equal to the marginal cost of the last needed electricity generation technology, otherwise called marginal plant, to meet electricity demand. Renewables penetrate into the supply curve of the day-ahead market with nearly zero marginal cost and thus get priority dispatch compared to other electricity generation technologies. Accordingly, they shift the supply curve to the right, resulting in a lower electricity price and complex electricity market dynamics.

The effects of renewables on electricity prices are of great concern, not only to energy market participants such as, for example, risk managers who must have a clear understanding of price dynamics, but also to policymakers who need to adjust the market design based on new challenges in order to improve market efficiency and thus social welfare. As Huisman et al. (2015, p. 151) recently put it, "an incomplete understanding of these relations could lead to an unintended outcome of the implied policy." Hence, as the role of intermittent renewables increases, it is expected to have remarkable and unprecedented effects on electricity price dynamics, while testing the adequacy and flexibility of electricity market design.

Germany is a pioneer country for renewables integration, and 2015

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http://dx.doi.org/10.1016/j.enpol.2016.11.014
Received 6 May 2016; Received in revised form 1 September 2016; Accepted 4 November 2016
Available online xxxx

has been a landmark year, with the growth of renewables in the power generation mix at its highest ever recorded. Energiewende (2016), a leading energy policy instrument in Germany, points out that “2015 goes down on record as the year in which renewables dominated the power system for the first time ever, becoming by far the most important energy source.” The large-scale integration of intermittent renewables has been a natural development in the German electricity industry, especially after its decision in March 2011 to scale down nuclear power plants. This transition of Germany's energy system, known as ‘Energiewende,’ has been assisted by the German renewable support scheme, which promotes investments in renewable energy generation through the implementation of policy instruments. Accordingly, we can safely argue that the German electricity market has experienced such drastic reforms during the energy transition, that nowadays it constitutes a different electricity market.

This paper contributes to the literature on the effects of renewable power on electricity prices in several ways. First, it fills the gap by disentangling the differential effects of solar and wind power on German day-ahead electricity prices, using daily data, which is as recent as June 2015. Apart from a few studies such as, for example, Clò et al. (2015), the majority of the literature focuses on the effects of wind power on electricity prices (because in past years solar power penetration was limited), or treats both solar and wind power as a combination under the name of intermittent renewables. Hence, they ignore the unique features of solar power as well as the corresponding implications for the power system; see Gullì and Balbo (2015). Secondly, since electricity supply nowadays consists largely of stochastic solar and wind power, while electricity demand is captured by electricity load, we are interested in exploring the dynamic relationship between day-ahead electricity prices and supply and demand forces in a multivariate context.

We estimate a univariate GARCH-in-Mean model in order to investigate the effects of solar and wind power on electricity price formation, and therefore explore their different implications in relation to market design. Only a few studies, with the most notable being Ketterer (2014), investigate the effects of renewables on day-ahead electricity price volatility, and most of them do not consider the recent period of high renewable penetration in the German electricity market. Finally, in line with Jónsson et al. (2010), we explore the impact of solar and wind power on the distributional properties of German day-ahead electricity prices, under different scenarios of solar and wind power penetration. By doing so, we understand better the effects of solar and wind power on the complex behavior of electricity prices, for instance negative or extreme prices, and consider it in relation to the market design and economics of the German power market.

The paper is structured as follows. In Section 2, we give an overview of the deregulation of electricity markets, the subsequent transition towards renewables, as well as the merit-order effect. We also discuss the new challenges of the German electricity market derived from the combination of large-scale integration of intermittent renewables and the limited flexibility of the electricity market. An analysis of negative electricity prices concludes this section. In Section 3, we describe the data and investigate their time series properties, while in Section 4 the effects of solar and wind power on the distributional properties of electricity prices are investigated. In Section 5, we present the GARCH-in-Mean model and discuss the empirical evidence, while in Section 6 we conduct a multivariate Granger causality investigation. The last section concludes the paper.

2. Challenges in electricity markets

Although electricity markets were traditionally designed merely for delivering electricity, nowadays they play numerous important roles in society. For example, sustainable development of energy supply, energy security, environmental protection, climate change mitigation, employment opportunities, and economic efficiency are some of their policy targets. In order to achieve these goals, electricity markets experience profound restructuring, with the most notable being their deregulation and the integration of renewable energy sources into their electricity production mix.

2.1. Deregulation and stylized facts

The deregulation of electricity markets has provoked fundamental reforms within their industries. Before deregulation, the electricity sector used to be vertically integrated and the public utility commissions set the prices in such a way as to ensure the solvency of the firm. Hence, price variation was minimal and under the rigorous control of regulators (Knittel and Roberts, 2005). After deregulation, however, competition was introduced and price variation rose significantly. Deregulation, in combination with the physical peculiarities and economics of the power system, introduced distinct dynamic properties in electricity prices, which are considerably different from those of financial assets (see Keles et al., 2013). These properties, or stylized facts, have been investigated by a substantial body of literature, including studies by Knittel and Roberts (2005), Higgs and Worthington (2008), Karakatsani and Bunn (2008), Escribano et al. (2011), and Fanone et al. (2013).

Seasonality is one of the most interesting characteristics of electricity prices, which is predominantly attributed to the highly inelastic short-term electricity demand (see Sensfuss et al., 2008). This can be viewed as a result of the limited efficient storage capabilities that preclude any kind of inventory strategy to be implemented in both the residential and commercial sectors. In combination with the transmission constraints and the instantaneous nature of electricity, any supply and demand shocks will be transmitted immediately to electricity prices, resulting in price spikes and high volatility. Ullrich (2012) investigates the realized volatility and the frequency of price spikes in eight wholesale electricity markets and underlies the need for better understanding of price spikes and volatility. Some other interesting studies on these stylized facts are Huisman and Mahieu (2003), Worthington et al. (2005), Karakatsani and Bunn (2010), and Efimova and Serletis (2014). Finally, mean reversion is another specific characteristic of electricity prices, mainly driven by weather conditions (Koopman et al., 2007); it refers to the tendency of electricity prices to revert to a long-run level reflecting the long-run cost of electricity generation.

2.2. Transition towards renewables

Although Germany had not been a pioneer country in the deregulation of electricity markets, as for instance the United Kingdom and Norway, nowadays it attracts special attention as a prominent example of a country integrating renewable energy sources. In fact, 30.1 per cent of its electricity in 2015 came from renewables such as wind and solar, up from 16.6 per cent in 2010 (see Table 1). This energy transition, known as Energiewende, is characterized by high growth in renewable energy, and is a natural development in the German electricity industry after the German government's decision in 2011 to phase out nuclear power. Therefore, significant changes have occurred in the German energy mix over the following years with the nuclear power generation falling by 21 per cent during the first year.

Germany achieved this rapid transition through a generous renewable support scheme that relies on three policy instruments: (a) fixed-feed in tariffs for renewables accompanied by a take-off obligation, (b) a priority dispatch for renewables, and (c) very restrictive rules for renewables curtailment that takes place only for security reasons — see Brandstätt et al. (2011) and Henriot (2015). Although this support scheme inspired confidence for investors, thus boosting renewable energy investments (Klessmann et al., 2008), it raised a broad discussion related to its high cost that consumers are eventually required to finance (Tveten et al., 2013). Some notable studies that