Energy Policy 117 (2018) 263–277

Contents lists available at ScienceDirect

Energy Policy

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

How renewable production depresses electricity prices: Evidence from the German market[☆]

Cyril Martin de Lagarde[a,b,*], Frédéric Lantz[c]

[a] *École des Ponts ParisTech, Cité Descartes, 6-8 Avenue Blaise Pascal, 77455 Champs-sur-Marne, France*
[b] *Université Paris-Dauphine, PSL Research University, LEDa, CGEMP, Place du Maréchal de Lattre de Tassigny, 75016 Paris, France*
[c] *IFP School, 232 Avenue Napoléon Bonaparte, 92852 Rueil-Malmaison, France*

ARTICLE INFO

Keywords:
Renewable energy
Intermittency
Electricity markets
Merit-order effect
Feed-in tariffs
Markov switching models

ABSTRACT

The urgency of climate change has led several countries to develop renewable energy in order to reduce CO_2 emissions, through the means of various subsidies. In the electricity sector, one drawback of such policies is the negative impact on electricity prices, known as the merit-order effect. This paper aims at assessing how intermittent renewable production depresses electricity prices in Germany, which has experienced a significant increase of its renewable capacity over the last two decades. To do so, we use a two-regime Markov switching model, that enables to disentangle the impact of wind and solar generation, depending on the price being high or low. We find as expected that renewable production induces a negative marginal effect, which is stronger in regimes of relatively high prices. In addition, we show that both wind and solar productions have a significant impact on the distribution of prices, and in particular on the frequency and expected duration of each regime. This has implications in terms of market design, security of supply, and support mechanisms for renewables.

1. Introduction

The development of renewable energy sources (RES) is often justified by the need to address global warming, through the reduction of green-house gases emissions, and is also led by the will to reach energy independence in fossil and fissile fuel-dependent countries. In the electricity sector, main RES are wind power and solar photovoltaic (PV). These technologies are spreading throughout the world and Europe, which has announced RES targets for the next decades: 20% in the final energy consumption by 2020 and 27% by 2030. To reach these goals, renewables often need to be subsidised, as they would generally not be competitive otherwise on the wholesale market.[1] In addition to the aforementioned goals, the subsidisation of these energies aims at internalising the "learning effect", i.e. the decrease of their cost along with their development. This is a positive externality that is by definition not taken into account by the market, and which would lead to too few investments in these technologies if not accounted for.

However, the development of electric RES challenges the current design of electricity markets. Indeed, they were originally designed to reflect the short-term production cost of electricity via the system marginal price, i.e. the marginal cost of the last unit needed to meet the demand. While marginal costs were traditionally driven by fuel costs such as coal, gas, oil, or uranium; wind and photovoltaic have on the contrary (almost) no marginal cost. Therefore, they tend to lower prices when they are producing, which is commonly known as the "merit-order effect" (Sensfuß et al., 2008). In addition, wind and solar energies are intermittent (or variable), albeit with seasonal patterns, while electricity prices are highly seasonal, with seasonality being driven mainly by demand at the daily, weekly and yearly time scales. Hence, RES generation is likely to have a different impact on electricity prices, depending on the state of the supply-demand equilibrium. Additionally, renewable production is expected to affect electricity also globally, and in particular its distribution, which is only partly captured by the analysis of the merit-order effect.

This article addresses these issues for the German day-ahead market by developing a two-regime Markov switching (MS) model. In particular, we are able to disentangle the merit-order effect in function of the price level, while keeping temporal coherence of the time series.

[☆] *This article is part of a Virtual Special Issue entitled 'Energy and Environment: Transition Models and New Policy Challenges in the Post Paris Agreement'*

[*] Corresponding author at: Université Paris-Dauphine, PSL Research University, LEDa, CGEMP, Place du Maréchal de Lattre de Tassigny, 75016 Paris, France.
E-mail addresses: cyrildelagarde@gmail.com (C. Martin de Lagarde), frederic.lantz@ifpen.fr (F. Lantz).

[1] However, distributed renewable generation such as rooftop solar PV is becoming more and more profitable for end-users, as their levelized cost of electricity (LCOE) can in some places be lower than the retail tariff they are faced with (grid parity). Such consumers, often called "prosumers", do not need to be subsidised by public funds (even though it is sometimes the case), but they can benefit from cross-subsidies via the distribution network tariff.

https://doi.org/10.1016/j.enpol.2018.02.048
Received 31 July 2017; Received in revised form 30 December 2017; Accepted 28 February 2018

Furthermore, we allow for time-varying probabilities (inhomogeneous model), in order to capture the impact of RES on the switching mechanism from “high” to “low” prices, and hence on the proportion and duration of each regime.

Studying the merit-order effect in Germany is quite relevant, as the country has had a huge development of wind and solar PV over the past two decades (RAP, 2015). Furthermore, since more than 40% of the electricity production in Germany (and Austria) is traded on the EEX day-ahead spot market, the related price is a relatively good indicator of the electricity supply-demand equilibrium. Hence, for these several reasons, the choice of Germany seems quite appropriate.

The remainder of the article is structured as follows. In Section 2, we briefly explain the mechanism behind the merit-order effect as well as other consequences of renewable production on electricity prices. In Section 3, we provide a review of the literature on the impact of RES production on electricity prices as well as on MS models applied to electricity prices and we explain which gap we aim at filling with this paper. Then, Section 4 briefly describes the data we used. Section 5 then presents the modelling strategy, and empirical results are presented and discussed in Section 6. Finally, Section 7 concludes the article by providing the main findings and policy implications.

2. Theoretical analysis

In this section, we use basic microeconomic tools to illustrate how the merit-order effect arises and why it is differentiated depending on the price level. We explain also how renewable production is likely to impact the distribution of prices more globally.

Graphically, we can see that if at the equilibrium the inverse supply curve[2] is locally steep, the impact is expected to be higher than when it is locally flat. In Germany, on average the steepness of the inverse supply curve increases with load, i.e. it is convex (except in the negative-price zone). It may not be the case elsewhere, but for example Karakatsani and Bunn (2008), show that in the British market the aggregate supply function is also convex. Fig. 1 illustrates this case by showing the variation of the merit-order effect with the load level.

Formally, this can be seen in the following way: if $D: p \mapsto D(p)$ (with $D' < 0$) and $S: p \mapsto S(p)$ (with $S' > 0$) are the expressions of the instantaneous demand and supply functions, the impact on the price of an infinitesimal shock of supply (e.g. RES production) or demand would be at the first order (proof in Appendix A):

$$\frac{\partial p}{\partial Load} = \frac{-1}{\dfrac{\partial D}{\partial p} - \dfrac{\partial S}{\partial p}} = -\frac{\partial p}{\partial RES} > 0 \tag{1}$$

In reality, supply and demand are piecewise constant functions, as they are the result of a bidding process. Hence they have zero derivatives except in points of discontinuity where they are non-differentiable. Nevertheless, it is convenient to assume differentiability as it gives the right insight, and in the case of rather small increments it is a good approximation. From Eq. (1), it is clear that the higher the slope of the inverse supply function S^{-1}, the lower the slope of S (equal to its inverse), and thus the higher the marginal (merit-order) effect. Note also that on average the impact of wind, solar and load has no reason to be the same, as all variables and the supply and demand functions vary over time. In addition to this marginal effect, RES production is expected to have a more global impact on electricity prices, in particular on its conditional or unconditional distributions. For example, we could expect prices to be “low” more often, especially if complementary sites can be used for RES installations. Also, conditional volatility is expected to be higher in periods of “high” prices (because of the same slope argument), while unconditional volatility can be lower or higher, depending on how much more “low” prices (with lower conditional volatility) there are.

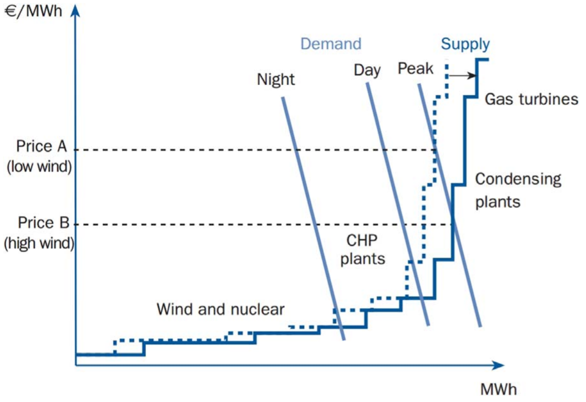

Fig. 1. Differences in the merit-order effect (source: Risø DTU).

3. Literature review

3.1. Impact of renewable production on electricity prices

The impact of subsidised renewable generation on electricity prices and its distributional implications have been widely discussed empirically and theoretically, e.g. by Meyer and Luther (2004), Munksgaard and Morthorst (2008), Gonzalo Sáenz de et al. (2008), Sensfuß et al. (2008), Cutler et al. (2011), Tveten et al. (2013), Cludius et al. (2014), Kallabis et al. (2016) and Bublitz et al. (2017). In this topic, the use of time series econometrics to study the market impact of RES production is more recent and very abundant as well. Many of them used ARMA-GARCH models, such as Woo et al. (2011) in Texas, Liu and Shi (2013) for the ISO-New England market, Ketterer (2014) in Germany or Karanfil and Li (2017) for the Danish intraday market, just to cite a few ones. All these analyses found a significant negative impact of RES generation on electricity prices and a positive one on conditional volatility (when modelled). However, the measured effect is necessarily averaged over the whole time series due to the used methods. Additionally, these studies mainly describe the merit-order effect, but do not tell how renewable production affects the proportion and duration of the price levels, which can be an issue for the profitability of plants relying on episodes of high prices.

Nevertheless, some authors have used other models in order to capture variability in the merit-order effect and additional properties. For example, Jónsson et al. (2010) quantify the impact of wind forecast on electricity prices for each hour of the day using a non-parametric approach. They also analyse the distributional impacts on the price under several scenarios, and show in particular that the unconditional volatility decreases with wind penetration. Unfortunately, they do not model the underlying mechanisms. In a different fashion, Paraschiv et al. (2014) estimate the impact of RES generation (and other variables) on electricity prices in Germany for each hour of the day, using time-varying coefficients. In particular, they show that the impact of wind (resp. solar) energy is more important during afternoon, evening and night hours (resp. noon peak hours).

However, electricity prices are expected to become less and less deterministic as the share of renewable generation increases and demand-response and storage become more available. This fact calls for a more flexible approach, which should be based on the level of prices rather than on predefined periods (hours, days, etc.). In this spirit, Keles et al. (2013) show that the wind power feed-in has a distinct impact on prices depending on the load and residual load levels (and hence implicitly on the price level) for each hour and day type. Their analysis is performed using linear regressions on ascending 2-MW load clusters, which are then used in a simulation of electricity prices. Unfortunately,

---

[2] The inverse supply function S^{-1} gives the price p in function of the supply quantity q. The inverse supply curve is thus defined by $p = S^{-1}(q)$.