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DOI: https://doi.org/10.14195/2183-203X_53_5

The Effect of Intermittent Renewable Energy Generation on Electricity Prices: A Literature Survey

Efeito do Incremento da Produção de Energias Renováveis Intermitentes nos Preços da Eletricidade: Revisão da Literatura

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Received for publication: June 15, 2020
Revision accepted for publication: April 9, 2021

ABSTRACT
Despite increasing deployment of intermittent renewable energies at lower generation costs, wholesale electricity price has been falling while retail electricity prices go up. This has triggered the debate on the cost-effectiveness of this source of energy. Therefore, the aim of this paper is to present a literature survey on the effect of intermittent renewable energy generation on electricity prices. Researches have used different methodological approaches, different periods and countries to examine the impacts of intermittent renewable energy on electricity prices. Most of the studies found evidence of the merit-order effect, which means that an increase in intermittent source generation would reduce the spot electricity market price. Finally, the few studies that address the retail market found that retail electricity could either increase or decrease.
Keywords: Electricity market; intermittent renewable energy; electricity prices.

JEL Classification: O38; Q41; L11.

Acknowledgement: The authors would like to thank to an anonymous referee for their comments and suggestions, although the usual disclaimer applies.

1. Introduction

The liberalization of many of the European electricity markets in the early 1990s promoted the development and deployment of intermittent Renewable Energy Sources (RES), both of which have increased significantly. This alternative has become one of the main targets of energy policy. Intermittent Renewable Energy is considered an important way to reduce energy dependence, deal with environmental issues, and to achieve sustainable economic growth.

Countries that have succeeded in increasing their renewable capacities significantly have implemented intensive support policies such as feed-in-tariffs (FIT) or renewable allowance systems which have significant costs. The RES penetration has raised the concern of costs of promotion, which have increased significantly for wind energy and solar PV. Therefore, the impacts of renewable electricity production in energy markets must be understood by assessing its effect on electricity prices and efficiency of renewable support policies.

The electricity production costs are expected to fall for renewables which could be explained by the decreasing costs of investment as technologies evolve. Consequently, this may reduce the need for subsidizing renewable energy technologies.

According to a recent report on energy prices and costs published by the European Commission the wholesale energy prices have fallen due to increasing competition on wholesale market namely from greater amounts of renewable energy.

Despite the fall in generation costs, renewable energy has driven up the retail electricity price and has been an expensive way to achieve greenhouse gas reductions which arises the debate on the cost-effectiveness of this source of energy. The costs of RES support are passed to electricity consumers in their bills and they are often regarded as a main driver of the increase of retail electricity prices.

Given the relevance that this matter has taken on, researchers have been carried out studies mostly applied to wholesale market. However, the studies applied to the retail market are still scarce. Therefore, the main aim of this study is to review the literature on the effect of intermittent renewable energy's generation on electricity prices at wholesale and retail markets.

This paper is structured in the following way. Section 2 presents the theoretical framework and describes the merit order effect. Section 3 shows some relevant studies that analyzed the effect of renewable energy at wholesale electricity price. Section 4 presents some works carried out to measure the effects of renewable energies on retail electricity price. Finally, the last section presents the conclusions and suggestions for future research.

2. Theoretical Frameworks

To understand the impact of renewable technologies on price formation, we start to describe the functioning of liberalized electricity markets. In Europe the liberalized spot electricity markets using a marginalist approach has prevailed.

Nowadays, the power market designs operate on the assumption that electricity generation has a range of positive marginal costs that increase through some rank ordering, as

is the case for thermal generators, based on technologies and fuel sources. This design is based on the construction of an efficient merit order through an implicit auction in the day-ahead market.

Economic theory predicts that high renewable electricity production reduces the wholesale price of electricity, which is commonly known as the merit-order effect. The merit order effect is a detailed analysis of the impact of renewable electricity generation on spot market prices. This effect is only one of several consequences of renewable production on the electricity system. Consequently, it is crucial to determine its size for the economic evaluation of renewable energies.

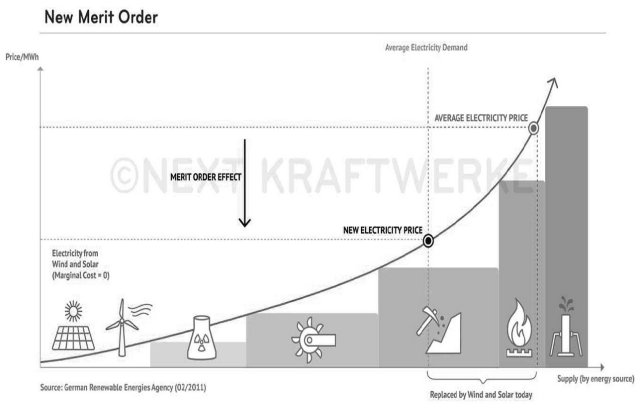
Theoretical considerations introduced by Jensen and Skytte (2002) suggested that renewable electricity production results in lower electricity prices. The merit-order effect means that the price decreases because (additional) renewable electricity bids into the market at lower marginal costs.

2.1. Merit order effect

In order to supply electricity, different power generation technologies compete with each other according to their availability of supply and their marginal cost of production (fossil fuels (coal or natural gas), nuclear power, renewable energy sources (hydroelectric generators, wind or solar energy)). Conventional approach consists in ranking the power plants of the system in ascending order of their marginal cost of generation. This approach is called the merit order effect.

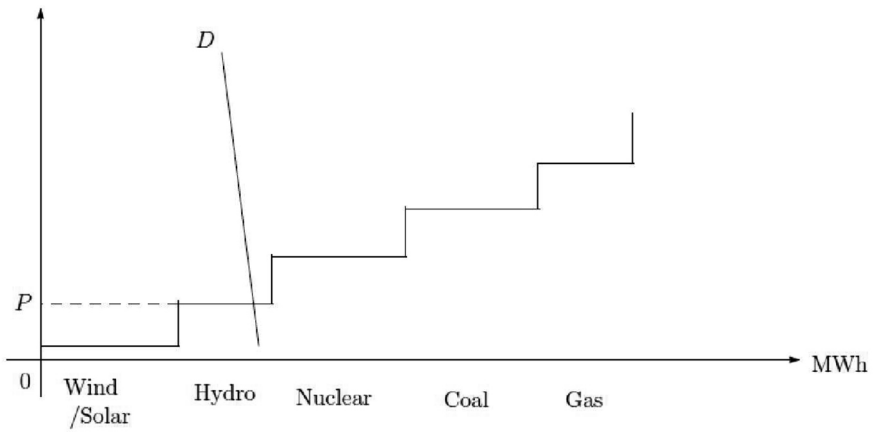
Merit order effect is used to describe the mechanism by which the market price is determined. The electric power price is set by the "merit order", of which the sources with the cheapest marginal costs will be sold more quickly. Conventional electric power sources (coal and gas) are crowded out along the merit order. Figure 1 shows the merit order effect.

Figure 1: Merit order effect



The merit order effect corresponds to the electricity supply curve. The demand side of the electricity market is assumed to be inelastic. This means that almost none of the buyers cannot respond to the spot price. The intersection between supply and demand curves is obtained the electricity market equilibrium (see Figure 2).

Figure 2: Electricity Market Equilibrium



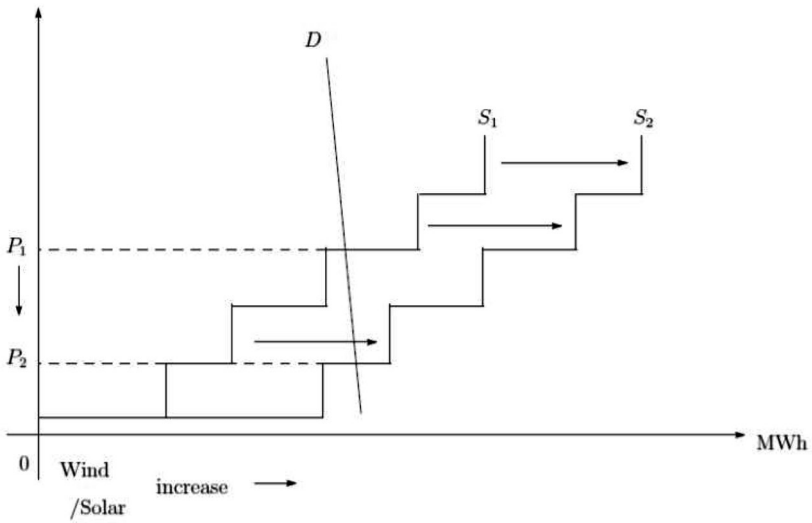
Source: Maekawa et al. (2018), figure 2.

Electricity supply has renewable energies and conventional energies. Renewable energies such as wind and solar are intermittent with large variability and unpredictability. In the case of intermittent renewable energies, the electricity supply heavily depends on environmental conditions such as rainfall, wind power and hours of solar radiation. Because these natural resources can be obtained freely the marginal cost of renewable energies is almost zero.

The merit order effect has gained increasing attention in the literature both on a theoretical and empirical context. Jensen and Skytte (2002) point out that RES generation enters at the base of the merit order function, thus shifting the supply curve to the right and crowding the most expensive marginal plants out from the market, with a reduction of the wholesale clearing electricity price.

An increase in renewable energies pushes the merit order curve (supply curve) S1 to S2 and the spot price falls from P1 to P2 (see Figure 3).

Figure 3: The price effect of increasing renewable energies



Source: Maekawa et al. (2018), figure 4.

3. Wholesale Market

Theoretical consideration introduced by Jensen and Skytte (2002) suggest that renewable electricity production results in lower electricity prices. This is explained by the fact that renewables bid into wholesale electricity market at almost zero price, and shift the electricity supply curve to the right.

Several researchers carried out empirical analyses on the impact of RES in electricity markets, finding evidence of the merit-order effect. This means that an increase in intermittent sources generation would reduce the spot electricity market price by displacing high fuel-cost marginal generation. RES installations, although they are very capital-intensive, have almost zero marginal generation cost and thus are certainly dispatched to meet demand. More expensive conventional power plants are crowded out and the electricity price declines.

Considering the wholesale market, Würburg et al. (2013) presented an overview of previous studies about the effect of intermittent renewables energies on electricity prices, grouping it in three categories: simulation-based; empirical; and studies with limited information on the price effects of renewables. Despite the different approaches, given the growing availability of ex-post data on electricity prices and renewable capacity, we focus the literature review on empirical approach.

Various papers found empirical evidence of the merit-order effect in various countries, namely Würzburg et al. (2013) for Germany, Gelabert et al. (2011) for Spain, Woo et al. (2011) for Texas and O'Mahoney and Denny (2011) for Ireland. These studies differ with respect to methodology used, types of renewable sources and country analysed, as well as frequency of the data used. However, there is a wide consensus that RES penetration has lowered wholesale electricity prices.

Würzburg et al., 2013 carried out an empirical analysis of the price effect of renewable production for the Austrian-German region. These authors proved that the merit-order effect varies depending on the region and the method chosen. They concluded that the merit-order effect is much larger for smaller markets opposed to larger markets. They found that for each GWh of average hourly predicted renewable energy generation the day-ahead electricity price was reduced by 2% for the German-Austrian market.

Using daily production quantities of different electricity generation types for Spain, Gelabert et al. (2011) investigated its effect on electricity prices during the 2005-2009 period. They concluded that each GW of additional renewable electricity production reduced Spanish electricity prices by roughly 2 €/MWh. A similar result was obtained by Sáenz de Miera et al. (2008) after picking three arbitrary days of February 2006 to perform an exhaustive comparison of electricity prices and wind energy production.

Woo et al. (2011) found that a 1 GWh increase in wind generation (during 15 minutes) decreased Texas balancing electricity prices between 13 and 44 US$/MWh.

Employing hourly data for Ireland, O'Mahoney and Denny (2011) explained the movements in the shadow price of electricity. They stated that a key challenge internationally is the design of future electricity systems which will bring about emissions savings and fuel security at least cost. Renewable energy is considered a viable alternative to conventional generation with zero or lower emissions. They found that the price of electricity fell by 9.9 €/MWh per GW of wind.

Clò et al. (2015) analyzed to what extent the penetration of solar and wind electricity sources has lowered day-ahead wholesale electricity prices and whether such a reduction has been sufficient to offset the cost of the RES support schemes sustained by final consumers. Based on Woo et al. (2011), Clò et al. (2015) developed a quantitative analysis to assess the extent to which variations in consumption patterns and in the energy mix have had an impact on the national wholesale electricity price. While previous studies focused on wind generation, or treated wind and solar generation jointly, they analyzed separately the differential impact of solar and wind generation on Italian day-ahead wholesale electricity prices over the period 2005-2013. Moreover, as RES production has increased greatly over the period analyzed, they were interested in studying whether the impact of intermittent RES on electricity prices level has varied over time.

Recently, Benhamd et al. (2018) carried out an econometric analysis for Germany, as a country with high penetration of renewable energy sources (RES), in order to investigate impact of wind energy and Photovoltaic feed-in on electricity spot price level, the so-called merit-order effect. They used an ARMA-X- GARCH-X modeling where wind generation and photovoltaic are considered as exogenous variables included in the mean and the variance equation, in order to assess the joint impact of RES on the electricity spot price level as well as on spot price volatility in Germany. They found that wind power and Photovoltaic feed-

in decreases electricity spot price. However, their impact on electricity spot prices volatility are quite different. The solar Photovoltaic power has a lowering on impact electricity price volatility whereas the wind feed-in get worse it.

In short, the previous works showed that higher intermittent renewable energy production was generally and consistently associated with reduce electricity prices, at least in the short term. According to Gelabert et al. (2011), the long-term effects may be different since the new generation mix and short-term lower prices influence investment decisions and thus future prices.

4. Retail Market

There are several empirical studies on the analysis of the impact of higher levels of intermittent RES generation (triggered by RES support schemes) on electricity prices. These studies on the merit-order effect focused on the impact of such generation on wholesale electricity prices, leading to the conclusion that it results in a reduction on those prices (Sensfuß et al., 2008, Sáenz de Miera et al., 2008, Gelabert et al., 2011, and Würzburg et al., 2013).

Since RES generation is generally supported with an add-on on the wholesale price paid by electricity consumers in their bills, the issue is whether the lower wholesale price is partially or totally offset by the RES support, leading to an increase or reduction in the retail prices. On this matter, there are still few empirical studies and there is no consensus on the conclusions obtained.

The analysis of the impact of RES support on retail electricity prices can be placed in the context of the regulatory analysis of the electricity sector. Electricity is characterized for being one of the most highly regulated sectors. Several regulatory variables can be considered as key drivers of retail electricity prices, including the promotion costs related to RES support, network costs, taxes and levies.

In the European Union (EU), retail electricity prices have significantly increased in the last decade as a result of different regulations raising the concern of policy makers. The growth in the support costs for electricity from renewable energy sources (RES-E) has often been singled out as a main driver of these prices.

Consumer decisions are taken on the basis of retail prices, which have not seen the same decreases as wholesale electricity prices. Inefficiencies within the retail price, such as "tariff structure, taxation and the lack of time-varying options" give incorrect price signals to the consumer.

Gelabert et al. (2011) and Würzburg et al. (2013) found that the reduction in wholesale electricity prices induced by higher RES production offsets the increase in final electricity retail prices induced by RES support schemes (subsidies directly paid by consumers in the final energy bill). They respectively conclude that in Spain and Germany the increase in electricity production from RES has generated a net benefit to consumers.

London Economics (2012) assesses the trends and position of the UK electricity retail market relative to comparable jurisdictions in terms of prices, competition and profitability in the period 1984-2010. The econometric analysis suggests that commodity input prices, fuel mix (electricity) and wages explain a large amount of the variation in retail prices for

both residential and industrial customers across jurisdictions and over time. However, neither of these studies analyze the relative importance of RES-E support with respect to other cost components of retail prices.

Moreno et al. (2012) developed an econometric panel data model to estimate the relationship between the household retail electricity prices and RES in the EU from 1998 to 2009. They concluded that the retail electricity prices increase with the deployment of RES (wind). They found that a 1% increase in renewable energy results in a 0.018% increase in household electricity prices. This small effect is mostly influenced by RES-E support schemes financed by the electricity market. Public RES-E support schemes may effectively mitigate the retail price increase.

Considering the Spanish market and "peak and off-peak prices" separately, Ballester and Furió (2015) found that an increasing share of renewable energy results in lower retail electricity prices in Spain for the period from 2010 to 2013. The opposite is true for the period 2002 to 2009, due to less intense employment of renewable technologies and higher price associated with these technologies during this period. The weight of RES increased from 29% to 59% from 2008 to 2013, consisting of up to 80% of the daily supply on occasion since 2011. They employed a model adapted by Cartea et al. (2005), a stochastic process with mean reversion that includes a discrete jump process, which allows for price volatility to be captured. They found that the relationship between the RES-E share and electricity prices is only significant for peak prices; significant positive relationships between thermal (coal and oil-gas), nuclear, hydroelectric, pumping hydroelectric, combined cycle, renewables and price volatility have been found; renewables are negatively correlated with upward jumps in peak prices and no significant relationship have been found considering off-peak prices.

European Commission (2016) stated that wholesale electricity prices have decreased significantly although retail electricity prices tend to increase due to the network price component, taxes, and levies.

Based on Moreno et al. (2012) and Iimura and Cross (2018) analyzed the effects of renewable energy on household electricity prices in liberalized electricity markets in 7 OECD countries. These authors found a strong path dependency for household electricity prices, while market reforms resulted in more significant price decreases than policy anticipated. The results obtained confirm that there is no significant relationship between higher prices and increased renewable deployment. They suggested that renewables are more likely to be traded with neighboring countries than deployed by the host country due to the merit-order effect.

According to Trujillo-Baute, et al. (2018), previous studies are inconclusive about the effect of the intermittent renewable energy share on retail electricity price as country-specific regulatory policy has a significant impact on retail electricity prices. These authors attributed the significant increase in retail elasticity prices to the increase in renewable energy sources.

A study carried out by Greenstone and Nath (2019) examined the effects of renewable portfolio standards programs adopted by 29 states and Washington DC. They concluded that these policies raised retail prices significantly and reduced CO_2 emissions only to a small extent. In the European Union as a result of different regulations, retail electricity prices substantially increased in the last decade raising the concern of policy makers. The main reason for such high prices is the growth in the support costs for electricity from renewable energy sources (RES).

Finally, Oosthuizen et al. (2019) analyzed the effect of the increasing intermittent renewable electricity share on retail electricity prices for 34-OECD countries, considering the change in market structure for 23 EU countries. The results showed that the influence of the renewable energy share in the energy mix to retail electricity prices is positive and statistically significant.

5. Conclusions

In the EU, a recent study on energy prices and costs highlights that the increasing in intermittent renewable energy generation has reduced the wholesale electricity market. Although the final consumers' price has increased as a result of different regulations raising the concern of policy makers and researchers. The growth in the support costs for electricity from renewable energy sources (RES-E) has often been singled out as a main driver of these prices.

Taking into account the aim of this paper, which is to present a literature survey on the effect of intermittent renewable energy's generation on electricity prices, numerous empirical studies have been undertaken on the merit order effect and results obtained are in line with expectations.

That being said, the question is whether the lower wholesale price is partially or totally offset by the RES support, leading to an increase or reduction in the retail prices. The empirical studies carried out to assess this question are still very few in comparison with the merit order effect. In addition, there is no consensus with regard to the conclusions obtained.

Given the interest and relevance of this issue for police makers, researchers and consumers (households and firms), as future work it is fundamental to carry out further empirical studies using panel data set and applying panel data techniques to evaluate the impact of intermittent renewable energy's generation on wholesale and retail electricity prices.

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