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Impacts of intermittent renewable generation on electricity system costs

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HIGHLIGHTS

- A successful deployment of VRES-E strongly depends on the economic cost of its integration.
- We estimate the sensitivity of balancing market requirements and costs to VRES-E.
- Integration costs depend on variability, predictability and system flexibility.

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ABSTRACT

A successful deployment of power generation coming from variable renewable sources, such as wind and solar photovoltaic, strongly depends on the economic cost of system integration. This paper, in seeking to look beyond the impact of renewable generation on the evolution of the total economic costs associated with the operation of the electricity system, aims to estimate the sensitivity of balancing market requirements and costs to the variable and non-fully predictable nature of intermittent renewable generation. The estimations reported in this paper for the Spanish electricity system stress the importance of both attributes as well as power system flexibility when accounting for the cost of balancing services.

1. Introduction

In recent years, there has been an unprecedented increase in the presence of renewable energies in electricity systems. Considering its benefits, not only in reducing greenhouse gas emissions from energy generation and consumption but also in reducing external dependence on imports of fossil fuels, their promotion has become a policy priority for governments all over the world (Mir-Artigues et al., 2015). In December 2008, the European Union (EU) adopted its Energy and Climate package, a framework where specific objectives in terms of overall share of energy from renewable sources (RES), GHG emissions reduction (compared to 1990) and energy efficiency were established. With regards to renewable energies, an ambitious target has been set. For 2020, a 20% share of renewable energy sources in final energy consumption has to be achieved. A direct consequence of this objective is that renewable energy sources (RES-E) in electricity generation are expected to expand from 20.3% of electricity output in 2010, to around 33% in 2020, in order to meet the objective set by the European Commission.

This promotion of renewable energy has had a predictable impact on energy market prices, the relationship between RES-E deployment and wholesale and retail electricity price being a current area of interest for researchers (Ciarreta et al., 2014; Costa-Campi and Trujillo-Baute, 2015; Edenhofer et al., 2013; Gelabert et al., 2011; Sensfuß et al., 2008). In general terms, consumers finally pay for support for renewable electricity in their electricity bills. Through the access tariffs the money to finance the burden associated with the promotion of RES-E promotion schemes is raised. At the same time, RES-E generation with priority of dispatch on the wholesale market displaces and reduces the demand for conventional electricity – with higher variable costs. The substitution of conventional generation plants by RES generation therefore reduces the wholesale marginal price (merit order effect). The combined final impact on consumers of both effects depends on whether the reduction in the wholesale electricity

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market offsets the increase in final price due to RES-E support mechanisms.

Nevertheless RES-E deployment involves other interactions that may affect final electricity prices. The growth in RES-E during recent years largely reflects the expansion of two main sources, namely, wind and solar power. In the EU the quantity of electricity generated from wind turbines has increased more than five-fold since 2002 and the growth in electricity generated from solar power has been even more dramatic, rising from just 0.3 TWh in 2002 to reach 71 TWh in 2012. These changes in the energy mix present profound implications for many aspects of power system operation and control (IEA, 2009; Perez-Arriaga and Batlle, 2012) due to the nature of both wind and solar technologies. Wind and solar photovoltaic (PV) generation are both intermittent technologies, which means that energy output coming from these sources is variable over time and non-fully predictable.

A high penetration of generation from variable renewable sources (VRES-E) imposes additional flexibility requirements on System Operators (SO) in guaranteeing instantaneous equilibrium between demand and supply (Ela et al., 2014; Frunt, 2011; Glachant and Finon, 2010; Haas et al., 2013; Hirth et al., 2015; Hummon et al., 2013; Vandezande et al., 2010). The variability of renewable generation requires that the power system be operated with a high degree of flexibility, so as to keep pace with the fluctuating net load, defined at each instant as the difference between total energy consumption and total variable renewable production. The application of these flexibility requirements can affect final prices and the costs of renewable market integration, such as balancing costs, need to be considered to compute the economic impacts of an increasing penetration of variable VRES-E on electricity markets. Due to this limited predictability and variability of VRES-E generation, SO might be required to provide significantly higher volumes of these ancillary services than in the past implying additional costs.

In this regard, drawing on real data for the Spanish power market for the period 1 January 2011 to 31 December 2014, the present paper aims to contribute to a better understanding of these economic consequences by evaluating the impact of VRES-E generation on balancing market requirements and costs. In this analysis, we disentangle the economic effect caused by the variability of the effect caused by uncertainty. In terms of system operation both intermittent characteristics are relevant, but given that even with perfect VRES-E generation forecasting, the variability of wind and solar PV output introduce additional system flexibility requirements. Variability and non-fully predictability stress the need for an appropriate number of reserve power plants with flexible dispatch capable of providing the necessary stability and ancillary services to deal with problems of electricity market balance. At the same time, given that the integration of variable generation in a power system non-only depends on both properties of intermittent generation, but also on the power system characteristics into which VRES-E is integrated, the analysis will take system characteristics in terms of flexibility and electricity demand into account. Although power system reliability and resource adequacy are complex elements of market operations and the RES integration cost is influenced by multiple factors, in this paper we examine individually the size of the impact of each attribute of the intermittent generation.

Although this study is applied to Spain the results are of general interest for other countries where the renewable promotion it is at early stages and VRES-E penetration is lower. In this sense, over the last decade Spain had become a leader country with respect to the introduction of renewable energies. The rapid development of renewables in Spain was a direct outcome of national energy policies including regulatory changes focused on facilitating the grid integration of RES-E production and economic and financial incentives.[1] This policy has encouraged, besides the country's great renewable potential itself, investment in renewable energy technologies resulting in an increase in the RES-E installed capacity. With 50,481 MW – including hydro – at the end of 2014 – Spain had occupied a privileged worldwide position in terms of RES-E installed capacity. In terms of output, Spanish RES-E generation has grown from 26 TWh in 2000 to 111 TWh in 2014, when it represented 42.8% of total electricity demand. Among the different RES-E generation technologies, wind and solar PV represented 52% of total RES-E production in 2014. The relevance of both technologies, characterised by their intermittency, presents important system operation implications.

In this way, the results based on one of the countries, within the EU, with the highest renewable power capacities, and one of the most significant wind and solar power generation penetration provides useful insight to other countries. Furthermore, Spain also makes a relevant case study because of the isolated nature of its electricity system, with low interconnection capacity with neighbouring countries (France, Portugal, Morocco and Andorra). This represents additional challenges when integrating electricity generation from variable renewable electricity sources.

Even though variability and non-fully predictability need not be a barrier to increased renewable energy deployment, at high levels of VRES-E market penetration a careful economic analysis of the implications in terms of system operation is required. A strong presence of intermittent renewable generation is changing the way power systems are operated and controlled. In this paper we contribute to this analysis by exploring the relationship between the operational costs of the electricity systems, the variability and uncertainty of VRES-E generation and the flexibility requirements of the complementary system necessary to balance the power system.

The remainder of this paper is structured as follows. Variables, empirical strategy, model specification and the data used are detailed in Section 2. Estimation results are presented in Section 3. The paper ends with a final section summarising research conclusions and presenting policy and policy implications.

2. Data and empirical strategy

As has been pointed out in the previous section, the electrical system has to be in permanent equilibrium. For this purpose, balancing power (regulating and frequency-control power) is used to quickly restore the supply-demand balance in systems after active power imbalances arise. Adjustment services managed by the SO (Lobato et al., 2008) are responsible for adapting hourly production programmes resulting from the day-ahead market to the requirements of demand and supply deviations in real-time, thus guaranteeing the above-mentioned balance and meeting the conditions of quality and safety required for the supply of electric power. In the process of programming the generation, the operation of the system is focused on three fundamental aspects: (a) the resolution of technical restrictions identified in the programming resulting from the day-ahead and intraday markets, and from the operation itself in real-time; (b) the management of the system adjustment services corresponding to the complementary services of frequency and voltage regulation and control of the transmission network; and (c) the deviation management process as an essential way of guaranteeing the balance between production and demand, ensuring the availability at all times of the required regulatory reserves.

[1] Spain basically followed the "feed-in-tariff" (FIT) policy approach based on the determination of a long-term fixed price for RES-E production or fixed premium tariffs paid on top of the spot market price for electricity.

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