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The impact of virtual power plant technology composition on wholesale electricity prices: A comparative study of some European Union electricity markets

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ABSTRACT

Virtual Power Plant combines a wide variety of distributed generation resources and operates them as a unified resource on the energy markets. It gives an economic opportunity to renewable energy-based distributed generation, such as photovoltaic, small hydro or wind, as it can build a bridge to the integration of renewable resources in the wholesale electricity market. In this market, changes in the offers of portfolio electricity technologies affect wholesale electricity prices, since marginal generation costs are transmitted through to the wholesale market.

This paper investigates the impact of energy-based distributed generation technologies composition on wholesale electricity prices variations of different EU energy markets by using a Maximum Entropy Econometric estimation procedure. To know how much each unit of electricity produced by each technology can alter the electricity price could be very useful to develop optimal strategies in an electricity technologies portfolio decision.

1. Introduction

European Union has shifted significantly toward a more decarbonized energy system with the introduction of emissions reduction policies which have meaningful impacts on electricity markets. For example, many EU countries have adopted support schemes to encourage electricity generated from renewable sources RES-E (see [1] for a review of support instruments). Under those supports, the number of renewable energy-based distributed generation (RDG) projects have become in the range of hundreds of thousands in a single country. Particularly, in Spain, the Spanish National Commission for Markets and Competition accounted of 60 000 photovoltaic plants (around 90% of them are connected to the electrical distribution grid) in 2014 in comparison with 10 000 plants that had been registered for 2006 [2]. In Italy, the electricity generation structure is currently characterized by having more than 700 000 distributed generation points as a consequence of the national RES-E support [3].

In this context, the rising of RDG plants increase the support cost, becoming an unsustainable long-term policy. For this reason, some of the EU regulators are reducing or stopping this support and other are linking the support to the return obtained by RDG in the electricity market. For example, the current Spanish Royal Decree 413/2014 [4] replaces the feed-in tariff and links the RDG supports to a collection of additional payments to what RDG producers receive in the electricity market at a reasonable return.

Thus, RDG is most exposed to electricity market and raises a number of challenges related to its integration in wholesale exchange market ([5] and [6] identify some of those challenges: (i) Under marginal cost pricing in competitive electricity markets the increasing offer of RES-E will reduce electricity price market-, turning renewable plants in less profitable,[1] and (ii) as RES-E production is variable it increases RES-E owners imbalance costs due to the forecast error. In this context, RDG has to find new solution to increase its economic viability and reduce its risks of unavailability and imbalance generation.

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[1] For example, [7] indicates that, under some forecasting scenarios about the RES-E penetration that wind and solar will generate 31% and 11% of electricity respectively 2050 ([8] presents a scenario of a Europe with a 100% renewable energy system for the 2050). [7] points out that, as result of lower prices when there is a lot RES-E, the market revenues of renewable will decline rapidly below the average market price. For wind and solar their market revenues will represent 50% and 90% of the average market price respectively.

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One solution is to combine RDG plants with fueled-based technologies plants or to combine RDG plants ([9] show applications of portfolio optimization to reduce the risk in the electricity sector). This combination can be done under the concept of Virtual Power Plant (VPP) that combines a wide variety of distributed generation resources (DG) and operates them as a unified resource on the energy markets (see [10] for a comprehensive review of VPP existing research and [11] for review of the value of aggregators in electricity systems). Commercial VPP has an objective to maximize an overall DGs portfolio profit function taking into account uncertainties as market price and RDG production, among others.

Regarding the market price, under VPP deterministic decision-making problems, the market price just appears the only uncertain parameter is most of the existing papers, but most of them consider VPP as price taker since wholesale prices are considered as exogenous inputs in their decision-making problem; for example [12] or [13] that assume that VPP "cannot resemble monopolistic behavior, i.e., have no considerable market power and thus they act as price-taker agents".

However, by aggregating DG units into a single market unit they can large enough for trading at the wholesale price similar to large-scale producer as [14] pointed out, following in changes in prices. In fact, few authors as [15] or [16] have studied the techno-economic impact of the VPPs considering that VPP is price-maker when it has sufficiently large number of distributed generating units able to alter the formation of the electricity prices.

This scenario is not very far from the real situation, as it is expected that in some countries RDGs units become very high, so its aggregation can have some degree of market power (for example, in Spain it is expected that DG will make up for more than half of the installed electric generation capacity in 2020, becoming the major part of this generation is renewable-energy based as [17] pointed out).

Under marginal cost pricing, changes in portfolio electricity technologies offers directly affect wholesale electricity prices, since marginal generation costs (including the primary energy cost and carbon emissions) are likely to be transmitted through to the wholesale electricity market (see [18] for a detailed discussion about the price formation in electricity markets).

Thus, this article analyses the impact of the variations of RDGs technologies on wholesale spot electricity market. To know how much each unit of electricity produced by each RDG unit can alter the electricity price could be very useful to develop optimal strategies in a commercial VPP portfolio decision.

Various papers focus on the analysis of the impact of renewable technologies and other influence variables on electricity prices at EU level. In that sense, [19] provide a comprehensive overview of some existing results for Germany, Spain, Denmark, Nordpool and Netherlands until 2012, although researches have continued intensively investigating about this topic: [20] estimate the effect of wind energy in the Irish and British wholesale prices; [21] assess the impact of wind generation on Irish electricity market prices and [19] estimate the effect of renewable production on electricity price in the German-Austrian market; [22] analyze the impact on photovoltaic and wind electricity generation on the day-ahead electricity price formation at EEX German; [23] quantify the effect of renewables on wholesale German prices; [24,25] and [26] study the impact of wind and photovoltaic energies in Italian wholesale electricity prices; [27] and [28] investigate the effects of solar and wind power generation on electricity price in Germany and Netherlands respectively. The case of Portugal was studied by [29] and [30]. In Spain, [31] and [32] focus on the effect of renewables energies on the Spanish electricity prices. Recently, [33] show the effect of the renewable capacity on wholesale prices for Germany, Italy and Spain.

Nevertheless, despite the ample literature studying the impact of renewable energies on electricity prices, (i) most of them restrict the analysis to wind, PV or all aggregated renewables and few of them attempted the analysis using the interaction of different types of microgeneration plants and other renewable and non-renewable energy sources. Moreover, (ii) the most of existing papers only analyze one European electricity market or a limited number of countries belonging to the same wholesale market so (iii) their comparability is limited as these studies differ with respect to types of renewable sources, country analyzed, econometric approach, and, as well as frequency of the data used.

Our paper aims to extend this empirical literature related to the analysis of the effect of RDG on wholesale electricity markets (i) by taking into account more number of disaggregated renewable sources (we consider not only wind and/or photovoltaic technologies but also and micro and small hydro plants that are not taking into account in other studies), (ii) by extending the analysis to several spot electricity markets and countries: MIBEL (Spain) APX ENDEX (Netherlands), GME (Italy), EEX (Austria), EPEXSPOT-EPEX (Germany and France), and (iii) by allowing the comparability of the results as the same econometric approach, as well as frequency and sample of the data used is considered for each country.

It should be noticed that the most world base data are annual base-data, it gives a homogenous information for each country, but limiting the ample of data. In this situation traditional estimation procedures of economic models may provide biased parameter estimations, among others, or not provide solution. In order to overcome the problem, the Generalized Maximum Entropy Econometric approach [34,35] is proposed. This methodology has been suitably applied by [36] and [37] and [38] to model Spanish household and industrial electricity prices.

This paper is divided into four more sections. Section 2 presents the first existing literature review about the use of electricity prices on maximization profit of VPP. Section 3 describes the model specification and sample data to estimate the effect of several DERs on European wholesale electricity prices. Section 4 describes the used Maximum Entropy Econometric procedure to estimate the electricity price models. Section 5 presents the estimated models for the considered EU spot electricity markets. Finally, the conclusion section completes the paper.

2. Literature review

Our paper studies the impact of the variations of renewable energy-based distributed generation technologies (RDG) on some European wholesale spot electricity markets. To know how much each unit of electricity produced by each RDG unit can alter the electricity price could be very useful to develop optimal strategies in a commercial Virtual Power Plant portfolio decision. As it was showed in the introduction section, there is an ample literature studying the impact of renewable energies on electricity prices [19–33], some of them providing a comprehensive review about the impact of renewables energies on wholesale electricity prices at European level. For example [19] and more recently the paper published by [23] in *Renewable and Sustainable Energy Reviews* journal. Therefore, this section provides a comprehensive overview about the treatment of wholesale electricity price in distributed generation portfolio aggregator (VPP) decision problem.

As it was stated in the introduction section some studies consider electricity price as exogenous input in VPP decision-making problems (VPP is a price-taker) and others considers that price is an endogenous variable (VPPs act as a price-maker).

Regarding the first type of studies, [39] study the formation of a VPP that maximizes its expected profit based on weekly pool participation, among others. For handling market price uncertainties, decisions are made based on the most credible realizations of the prices. In that sense, [40] use a price confidence interval for the VPP decision-making tool for weekly pool participation but also for daily participation. Both studies consider that pool prices are exogenous inputs in the VPP decision-making process, so VPP acts as a price-taker agent. [13] study the reasons behind the profit of the aggregation of DGs under a VPP figure to participate in either wholesale markets or retail markets (under predetermined tariffs). They assume that such coalitions act as price-taker agents as have no considerable market power (they cannot