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Deciding on the support schemes for upcoming wind farms in competitive electricity markets

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ABSTRACT

A variety of policies have driven escalated global growth of wind-power generation in recent years. However, wind production should be supported through market-based schemes that avoid over-compensation. The present paper aims to determine a justified support scheme for upcoming wind farms in competitive electricity markets. Clustering tools and non-parametric regression algorithms are employed to model the price-formation process in the market and estimate the revenue of forthcoming wind facilities. Accordingly, the premium paid to an upcoming wind farm is calculated by incorporating its estimated revenue and levelized cost of energy. Then, the impact of the proposed wind project on wholesale and retail electricity prices is modelled based on the achieved non-parametric regression models. The methodology is applied to two wind farms in the Alberta and Ontario electricity markets in Canada as the case studies. Our results indicate that electricity consumers in Ontario should pay a higher premium for each unit of energy generated by the wind farm due to its lower revenue from the market. However, it is observed in both markets that the impact of wind farms on wholesale prices exceed the remuneration paid to them and thus, electricity consumers experience a decrease in their ultimate electricity costs.

1. Introduction

A variety of policies have driven escalated growth of Renewable Energy Sources (RES) technologies in recent years. Government economic promotions have been aimed at compensating for the relatively lower revenue of RES from electricity markets due to their small capacity factors. As of year-end 2015, at least 164 countries had renewable energy targets, and an estimated 146 countries had Renewable Energy (RE) support policies in place. Different jurisdictions have adopted various forms of renewable energy incentives, including blending mandates, quotas, portfolio obligations, tax credits and Feed-In-Tariffs (FIT). These incentives are in practice to offer a higher return than market prices, to offset higher costs of RES. Some support schemes such as tax credits are funded by governments. However, end-users pay the remuneration for other scheme like feed-in tariffs, blending mandates or quota obligations [1].

FITs are increasingly considered the most effectual policy at encouraging the expeditious expansion of RES and are currently implemented in 63 jurisdictions worldwide [2]. In FIT support schemes, remuneration is paid by the end-users [3–5]. Thus, consumers costs are the result of adding up the amount paid for RE support to wholesale electricity prices. Hence, there is a concern that support plans may place a financial burden on the electricity end-users. One of the most fundamental design challenges for a FIT policymaker is how to determine the actual FIT payments awarded to project developers for the electricity they produce. The remuneration paid to RES developers can be specified to represent the levelized cost of RES or as another approach the value of the RE generation either to society or to the utility [6].

Recent studies suggest that among different FIT policies, those that are based on RE project costs have be more effective in meeting deployment objectives. This stems from the fact that by adopting this policy, developers are assured that the revenues earned from the overall electricity sales are sufficient to recover their investment costs [7]. Thus, a justifiable support scheme for RES can compensate for the difference between their revenue and cost per MWh of electricity generation. Hence, a key factor is to estimate the revenue that RES can earn by participation in the pool-based market without income from subsidies [8], referred to as the

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"market value". It should be also noted that RES have mainly low marginal costs and displace the costly fossil-fueled thermal generators in the supply stack. Thus, higher available RE generation reduces wholesale electricity prices [3–5,9–21], which is in favor of electricity consumers. From a consumer's perspective, this reduction offsets the increase in final electricity prices resulting from the RES support. It is a subject of interest to know how much higher RE generation levels would decrease wholesale electricity prices. This would make it possible to investigate the final impact on retail prices paid by end-user electricity consumers by incorporating the RES support cost.

Among different RES technologies, wind-power has observed the highest installed capacity growth in the last decade with a 10-fold increase since 2004 [22]. There were more than 200 million wind turbines operating across the globe, with a total capacity of 432 GW at the end of 2015 [23]. World-wide wind-power capacity is expected to grow to around 630 GW by the end of 2019 [24]. Wind production should be supported through market-based schemes that avoid overcompensation. The existing literature on the effect of large-scale wind-power integration on electricity markets is based on either simulating market operation [3–5,9–15] or correlating price variations to wind-power fluctuations through econometric models [16–21]. In simulation-based models [3–5,9–15], operation of an electricity market is formulated as an optimization framework and wind-power is integrated in the operation model. For different scenarios of wind-power development, market clearing prices are obtained which in turn can result in the revenue and operation cost for each type of generation.

In one thread of research [3,4,9–13], a perfectly competitive market structure is assumed, and market supply curves are built based on the marginal costs of conventional generators. These studies disregard the collateral effect of market agents' behaviors. In other papers [5,14,15], a numerical supply function equilibrium model is used which allows for imperfect competition between generating firms. These studies [3–5,9–15] simulate system operation chronologically to minimize the total cost of supplying electricity demand. Wind is considered as negative load and a number of studies are conducted for a certain range of wind-power penetration. These frameworks need to have access to the restrictive information about cost function, ramp limit, and power rating of each power plant participating in the market. Bode in Ref. [3] has considered linear functions to model the aggregated supply and demand in the German market to investigate the impact of renewable energies on electricity prices in the wholesale market. Supply stack is constructed based on marginal costs of generation units in Ref. [4] and duration curves are built to model the electricity demand in the Spanish market. For certain level of wind penetration in the market, the demand duration curve in reconstructed to investigate the impact of wind generation on electricity prices. In Ref. [9], an agent-based simulation framework is developed to analyze the impact of renewable electricity generation on spot market prices in the Germany. Authors have formulated an optimization problem in Ref. [10] to simulate the market clearing process and wind generation is considered as negative demand to investigate its impact on locational marginal prices. In Ref. [11], the impact of wind generation control strategies, penetration level, and installation location on electricity market prices are estimated by running an optimal power flow. Unit commitment is formulated as a mixed integer linear programming problem in Ref. [12] and the effect of wind generation on market clearing prices and emissions level is studied. Authors in Ref. [13] have solved a unit commitment problem to model the German market with and without wind input to estimate the net savings of fossil fuels. A main concern is that these studies [3,4,9–13] disregard the collateral effect of market agents' behaviors by assuming a perfect competition in an electricity market. In Refs. [14,15], authors use a market equilibrium model which allows for imperfect competition between generating firms. Then, they calculate how the mix of generating capacity would change if large amounts of intermittent renewables are built in Great Britain, and what this means for operating patterns and the distribution of prices over time. A computational model is developed in Ref. [5], which includes ramping restrictions and costs and apply it to the German case. It is found that due to current wind supply the market prices are reduced and the incentives to invest in natural gas fired units are largely reduced. A criticism directed to simulation-based models [3–5,9–15] is that these frameworks need to have access to the restrictive information about cost function, ramp limit, and power rating of each power plant participating in the market. Another concern is about the practical application of proposed approaches in real electricity market with large number of participants, where solving the formulated optimization problems can be extensively laborious if not impossible.

In the second group, unlike the simulation-based papers [3–5,9–15], econometric-based methods are used to relate actual observations of electricity prices to wind-power generation. A rigorous statistical theory is typically applied to determine the effect of the independent variable, i.e., wind-power, on the dependent variable, i.e., the electricity price. Econometric models have been postulated and estimated to analyze the impact of wind generation on the wholesale electricity prices of Pacific Northwest [16], Texas [17–19], Pennsylvania-Jersey-Maryland (PJM) market [20], and Spain [21]. These studies [16–21] do not intend to simulate electricity prices for different scenarios of wind generation development and thus, are not able to estimate the revenue of individual wind farms. They normally present a final number as the overall average impact of wind generation on electricity prices without taking into account market conditions in their modeling. A main concern is the capability of these approaches [16–21] in estimating the actual observed price impacts of wind-power that are calculated from real supply curves in the market.

The present paper aims to determine a justified support schemes for upcoming wind farms in competitive electricity markets by incorporating their estimated market value and also their costs. In summary, the main contributions from this work are three-fold:

1. A data-driven approach is proposed to model the price-formation process in competitive electricity markets based on publicly available data. This model will enable us to estimate the revenue of upcoming wind farms by generating future scenarios of the data. The justified premium to be paid to each individual upcoming wind farm is then determined based on the difference between the Levelized Cost of Energy (LCOE) and the estimated revenue per unit of energy.
2. The impact on wholesale prices of forthcoming wind farms is investigated by integrating market operating regimes into our assessment. The price impact of wind-power generation is tied to market conditions, i.e., while wind-power availability may not necessarily impact the prices in certain conditions that electricity demand is low and available generation is high, it may significantly shift the prices under peak-demand periods that supply excess is low. We verify the effectiveness of the proposed approach by comparing the estimated price impacts with the actual observed ones in the electricity market. The real price impacts of wind generation are calculated based on the historical supply curves that are constructed from submitted generators' offers.