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Large-scale wind power in electricity markets: Editorial

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Introduction

This special issue of Energy Policy focuses on the following: how to integrate efficiently and effectively large-scale wind power in electricity markets? When marginal, wind power can be absorbed by power systems and existing markets without any major problem. However the impressive development of wind power technology during the last decade and its future role as one of the major contributor in the "Towards 2050" energy mix change this context. Thus integrating large-scale wind generation presents unique challenges due to the characteristics of wind power, including its low marginal cost, limited "*dispatchability*", variability in generation, difficulty in forecasting resource availability, and the particular geographic location of wind resources. Implementing large-scale wind power supposes to review the electricity market design, the wind support schemes as well as the way competition and strategic behaviors on energy markets are analyzed and modeled. Wind integration into competitive markets faces challenges with existing market architecture. One should share the corresponding system costs between system operator, wind power producers and network's users, and effectively manage the impact of wind production time-profile on the rest of the power system and markets. It is what this special issue aims at doing by presenting a variety of perspectives and reflecting the current state of the debate.

David Newbery gives this special issue an introductory paper highlighting the main consequences of large-scale wind power penetration in Europe and shedding light on academic topical researches needed in this new area. Moreover, D. Newbery proposes a comprehensive market framework adapted to efficient renewables support and integration into electricity markets. The other author's contributions are organized in three parts corresponding to three dimensions of the integration of large-scale wind power into electricity markets: (i) the adequacy of electricity market design and support schemes with large-scale wind power, (ii) the impact of wind power on markets outcomes and (iii) new methodologies to assess the wind power economic properties.

Adequacy of electricity market designs with large-scale wind power

The first part includes seven papers dealing with the adequacy of electricity market designs and support schemes to accommodate large amount of wind power. Market rules governing electricity transactions have to be designed to send right economic signals to market participants, whatever technology they use. With wrong signals market participants will behave inefficiently in the short-run or in the long-run. The first four papers analyze how to design electricity markets and support schemes to enable large scale wind power integration. The next three papers illustrate case studies pointing out how wind power producers have been integrated into competitive markets.

In the first paper ***C. Hiroux and M. Saguan*** wonder if the current European renewable support schemes and electricity market designs are well-suited to host a significant amount of wind energy. They argue that the key to build an adequate framework is to find the right equilibrium between the market signals sent to wind power generators and the intrinsic risks they faced. As long as wind power producers are sensitive to market signals, the market should bring adequate incentives for reducing the wind integration costs. However, too risky market rules may undermine the effectiveness of support schemes. The authors point out that several alternatives combining support schemes and market signals could improve the current situation. They conclude that 1° feed-in premium support scheme seems to be the more balanced option in terms of market signals and risks, that 2° wind generation technical management has to be shared between the System Operator and the wind power producers to help controlling wind integration costs.

The three following papers look at the design of specific parts of the electricity market architecture, namely: (i) balancing markets, (ii) intraday markets and (iii) congestion pricing. ***L. Vandezande et al.*** focus on the design of balancing markets. They point out the importance of allocating balancing costs to the responsible parties when there is a high wind power penetration. They argue that full balancing exposure is however only feasible with well-functioning balancing markets, given the variability and limited predictability of wind generation. Then the authors draw recommendations to ensure an optimal balancing market design and assess its impact on wind generation. They demonstrate that: (i) the imbalance settlement should not contain penalties or power exchange prices, (ii) operating reserve payments for availability should be made to imbalanced responsible parties (BRPs) via an additive component in the imbalance price and (iii) regulator should imposed a cap (or due incentives) on the amount of contracted and used reserves. Some of these recommendations could impact negatively the revenue of wind power producers, it highlights the importance of a greater geographical integration of balancing markets.

Ch. Weber points out the importance of intraday market liquidity to absorb larger amounts of wind energy. He analyses liquidity issues on the spot and intraday markets as linked with market designs of European power markets. He highlights the discrepancy between the physical short-term adjustment needs and the traded volumes on the intraday market. He proposes how to improve the liquidity on the short-term market, like the use of continuous spot trading like in UK or the use of intraday auctions like in Spain. The latter seems to be the most attractive way to increase liquidity.

H. Weigt et al. analyze the impact of extensive wind development in Germany by 2015, by focusing on the design of congestion price signals and on grid extension. They use an optimization model (ELMOD) with a detailed network model to compare zonal, nodal, and uniform congestion pricing. To a reference case of network extensions from the German Energy Agency (Dena), they add a scenario to transmit wind energy to major load centers via high voltage direct current (HVDC) connections. From a technical standpoint, they conclude that HVDC connections are the most economical way to integrate large-scale offshore wind resources, and that nodal or zonal pricing are more likely to induce locations of investment taking care of congestion.

These theoretical recommendations are completed with three case studies combining high participation of wind power producers into electricity markets and innovative schemes for efficient integration as in: (i) Spain, (ii) Australia and (iii) Texas.

There is currently 15 GW of wind power installed capacity and projected targets of 20 GW and 40 GW by 2010 and 2020 in Spain. ***J Rivier*** shows how the increase of wind market participation and the use of innovative solutions for technical and economical integration have allowed reaching such high level wind penetration. It points out that the evolution from a pure feed-in tariff to a market-based price and premium option has been crucial for market integration. It ends sending signals to participants to look for optimal technical solutions without hurting wind power investment. Rivier highlights the importance of establishing a regulatory framework that allows the System Operator to share wind units dispatch responsibility with producers.

Australia has been an early and enthusiastic adopter of both electricity industry restructuring and market-based environmental regulation. ***I. MacGill*** presents wind integration in the Australian National Electricity Market (NEM), describes the evolution of market rules in response to the increase of wind power share and assesses how they could facilitate high future wind penetrations. He points out that wind project developers must take into account both zonal energy market and Tradeable Green Certificate income streams when making investments. The wind farm energy income depends of its uncertain time varying output and the regional zonal half hourly market price. That price shows daily, weekly and seasonal patterns with a high uncertainty increasing the risk supported by wind developers. Recent NEM rule will formally integrate wind generation in the market's scheduling process while a centralized wind forecasting system is been introduced. MacGill's paper also discusses the governance of markets rule changes in the NEM market, including the participation of the main stakeholders and a clear definition of changes' procedure, as a requirement for efficient market ruling.

Texas is the first area in the United States with high penetrations of wind power. Since 2002 Texas deals with considerable challenges to accommodate aggressive renewable portfolio standards in a competitive electricity industry. ***R. Sioshansi and D. Hulburst*** discuss the design of market rules (protocols) taking into account the special characteristics of wind generation and survey the regulatory and market rules in Texas. They show a trade-off when applying special market rules to wind power generators. On the one hand, special rules allow to mild the integration of wind power considering its own special characteristics. However, on the other hand, special rules can create perverse incentives leading wind power generators to "gaming" the system. It has been the case with scheduling rules giving incentives to wind generators to over-schedule their generation to receive more balancing energy revenues. A new nodal market design, to be launched in 2010, will avoid these perverse effects. Nodal pricing should also incentivize wind power generators to select more adapted locations. However, high volatility of nodal prices in congested areas may have negative consequences on the development of wind power. Both ERCOT the system operator (and future market operator) and the regulator are looking how new methodologies for transmission planning could ensure that transmission capacity will be available for new wind generators.

The impacts of large-scale wind power on market outcomes

The second part of the special issue is dedicated to the impact of large scale wind power on market outcomes, mainly electricity prices and the strategic behavior of market participants. ***K. Neuhoff and P. Twomey*** show theoretically how equilibrium electricity prices are impacted by intermittent wind generation in presence of market power. Market power can exaggerate the effect of lower average market prices with intermittent generation technologies as compared to the average market prices received by conventional generation. Indeed conventional generators with market power can further depress the prices if they have to buy back energy at times of large wind output and can increase prices if they have to sell additional power at times of low wind output. Forward contracting, a typical instrument to mitigate market power, does not reduce this effect. As a consequence, allowing market power profit margins as an implicit support for generation capacity investment is not a technologically neutral policy.

R. Green and N. Vasilakos evaluate the impact of intermittent wind generation on hourly equilibrium prices and output, using data on expected wind generation capacity and demand for 2020 for Great Britain. They find that large amount of wind power projected for 2020 will increase considerably the volatility of prices, with a significant year-to-year variation in generators' profits. Moreover, they show that, if significant market power, price level could double and volatility increase. While wind generators' average revenues should rise by 20% less than those of conventional (baseload) plant. Such results reproduce what was theoretically deduced by *K. Neuhoff and P. Twomey*.

New methodological tools for optimal wind deployment

The last part of this special issue focuses on new methodological tools to assess the wind economic properties influencing optimal deployment. As wind interacts with other conventional technologies and markets, methodologies have to be updated and adapted.

G. Lewis proposes to address sitting issues of wind power taking into account the current scarcity of transmission capacity. His methodology uses locational marginal prices (LMP), the location and time specific cost of electricity on the wholesale market, to signal locations where generation can address electricity system insufficiency. That methodology is applied to LMP in Michigan over the first two years of wholesale market operation, combining LMP with wind speed data to generate a value metric. Higher value sites tend to be with higher wind speeds, with the bulk of value accruing in the fall and winter seasons. However these calculations indicate that locational signals sent by LMP may not be the most relevant when valuing wind resource.

N. Boccard proposes to evaluate economic properties of wind resources. His methodology assesses the system value of intermittent wind power as the cost of replacing its output, hour by hour, using thermal technologies. The system value depends then on the concomitance of intermittent wind power with load. The author defines social cost of wind power as the difference between its system value and its actual cost. He separates the social cost between a technological component and an adequacy component. Whereas the former component may become negligible once thermal technologies pay for a high CO2 price or once the cost of wind turbine decreases, the latter is a lower bound on wind power generation structural weakness vis à vis thermal technologies (i.e. the intermittency). He applies this methodology to Germany, Denmark, Spain, France, Portugal and Ireland using hourly load and wind power data over several years. He finds that the system value of wind power varies from three quarters of the equivalent thermal cost of electricity (on a yearly basis) with the incompressible adequacy cost (being a premium over the cost of serving yearly load in a system) ranging around one fifth.

Finally, ***F. Roques et al.*** apply Mean-Variance Portfolio theory to identify cross-country portfolios that minimize the total variance of wind production for a given level of production. This methodology allows assessing the benefits of geographic diversification of wind farms smoothing out fluctuations in wind power generation and reducing the associated system balancing and reliability costs. Their methodology allows also deriving optimal constrained inter-country portfolios taking into account national wind resource potential and transmission constraints. The authors use historical wind production data from five European countries (Austria, Denmark, France, Germany, and Spain). Their results show that there is still considerable room to improve performance from actual or projected portfolios. They also show that optimal portfolios integrate not only countries with the best wind resource but also whose size contributes to smoothing out the output variability or those that are weakly correlated with best wind resource ones. These results highlight the need for more cross-border interconnection capacity, greater coordination of European renewable support policies, as well as renewable support mechanisms and electricity market designs both providing locational incentives.

Concluding comments

All these papers suggest that large-scale wind energy integration in electricity market brings economic challenges on several dimensions being: market design and market rules, support scheme design, strategic behavior under presence of large-scale wind energy, and new methods for assessing wind power economic values.

Theoretical analysis and empirical experience also show that there are two main aspects into efficiently and effectively integrating large-scale wind power into electricity markets. On the one hand, more market participation of wind power producers and better market designs should enable the efficient integration of wind power through decentralized market signals. On the other hand, more centralized solutions (as central forecasting of real time generation, technical protocols delegating dispatch responsibility, transmission & distribution planning – being based on system operator's authority-) can be useful too. They can improve coordination where market signals are not emerging or adequate. The evolution from the existing frameworks to more efficient ones also has to keep enough stability to this high capital intensive investments industry.

Hosting large-scale wind power into electricity markets implies deep changes for market participants as more volatile electricity prices. An in-depth understanding of all these changes is needed to foresee their short-run and long-run consequences. The long-run impact of large-scale wind power still has to be better studied. We notably need to better understand how investments in conventional technologies will respond to the new pattern of prices (both to contribute to total capacity and to bring on line more flexible dispatchable technologies).

New methodologies should also be used to assess economic properties of wind resource and to design support schemes promoting efficient deployments of wind power. Such new methodologies are needed to optimize the use and the development of power networks (transmission and distribution) with large amount of intermittent renewable energy. It should cover the incentives for regulated transmission and distribution companies to respond to these new operational and planning methodologies. To end: a lot of further research is needed in many directions. Research is not gone with the wind…

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