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It is windy in Denmark: Does market integration suffer?

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ABSTRACT

Some benefits of spot electricity markets integration include the optimization of renewable power, increasing transmission grid security and the decreasing need for internal generation reserves. The high penetration of wind power is known to have a clear influence on price convergence between electricity markets joined by market splitting. However, in multiple interconnected markets, cross-border flows can also play a role in the market splitting behaviour. Denmark, with a high penetration of wind power, is clearly the ideal case study. This paper aims to assess the influence of high penetration of wind power on the market splitting behaviour between West and East Denmark, taking into account cross-border electricity flows. This is modelled through logit and non-parametric models, estimating the probability of market splitting occurrence between both Danish bidding areas. Market splitting probability is found to be sensitive to wind power, nevertheless with distinct behaviour according to interconnection congestion configuration. The highest availability of wind power in West Denmark, which can reach a generation share of 1.5 times the demand, requires strong cross-border interconnections to allow the export of the excess generation. Policies governing a joint assessment of the requirements for additional interconnection and wind power expansion plans, should be developed.

1. Introduction

The fast expansion of renewable generation, resulting from the transition to a post carbon society, is creating one of the most demanding challenges to transmission grids and their operation [1–5]. In addition, the integration of the European electricity markets through HV (High Voltage) cross-border interconnections, is a substantial part of the European internal energy policy [6,7], aiming to offer numerous advantages under normal operating conditions, such as optimal power station daily production, increasing opportunities for operation with renewable energies, the promotion of competition and enhancement of supply security. However, cross-border interconnections are limited and congestions can arise in multiple operation conditions.

One of the best case studies, considering the high level deployment of wind power and with a long history of electricity market integration through market splitting, is Denmark. Its support to research and technological development of wind power, resulted in a strong player in the wind power turbine market, supplying about one third of the world demand for this technology [8,9].

Literature can be found regarding electricity market integration in different geographic areas. US regional electricity markets integration is studied in Refs. [10,11], using spot market electricity prices, the first through cointegration and a vector error correction model and the second through a vector auto-regression model. Electricity market integration in Australia is assessed in Refs. [12,13], through the use of MGARCH (Multivariate Generalized Autoregression Conditional Heteroskedasticity) models, to include time-varying conditional correlation spillovers across electricity markets and better describe price and price volatility interrelationships. Electricity market integration in Europe was assessed by a significant number of studies and these are unanimous in establishing that there is electricity market integration in the North European regional electricity market, the Nord Pool, which is composed currently by Norway, Sweden, Finland, Denmark, Lithuania, Estonia and Latvia. However, by using Markov switching fractional cointegration, Ref. [14] found that cointegration exists only when interconnections between bidding areas are

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not congested in a detailed analysis to the electricity price pairs West Denmark – Norway and East Denmark – Sweden. Furthermore, Ref. [15] used a PCA (Principal Component Analysis), unit root tests and a convergence test based on filtered pairwise price relations of wholesale electricity prices, demonstrating that convergence between both Danish bidding areas and between East Denmark and Sweden had been achieved. However, Ref. [16] through the use of cointegration and unit root analysis, found the Nordic electricity markets not to be integrated with Germany and the Netherlands. In an assessment of European spot electricity markets convergence, Ref. [17] used a fractional cointegration analysis and a MGARCH model, to report that Nord Pool is fractionally cointegrated with the remaining analysed electricity markets (Austria, Belgium, Czech Republic, France, Germany, Greece, Ireland, Italy, Poland, Portugal, Spain, Switzerland, the Netherlands and the UK), and that perfect integration had not been achieved. A summary table regarding the above studies can be found in Appendix B for easier reference.

Also, literature focussing the impact of high penetration of wind power can be found. Highlighted issues in Ref. [18] are: the importance of adequate interconnection and transmission capacities; the capacity incentives for dispatchable power plants; demand management, reduce electricity trading constraints and further research on energy storage technology. Moreover, Ref. [19] highlighted the risk of excessive production, the use of energy storage and exports through interconnections to address balancing issues, appropriate system security and ancillary services; and Ref. [20] stressed the importance of enough dispatchable backup capacity with fast response dynamics, system robustness and reserves to cover uncertainty and/or withstand eventual electrical faults, and adequate transmission grid capacities to transport eventual excess renewable generation; the importance of wind power forecasting, allowing for load management and system balancing, is highlighted in Ref. [21]. Furthermore, Refs. [22–32] all reported some level of decrease on the electricity spot market prices due to the increase in the share of RES-E (renewable energy sources electricity) generation. This is explained due to the almost inexistent marginal costs, associated bidding into the spot electricity market and the resulting merit order of power plant dispatch, which displaces higher marginal cost fossil fuel power plants. The influence of the existing high wind power penetration on the behaviour of electricity price differences was studied for the four ERCOT zones of Texas by Ref. [33], through the use of ordered-logit and log-linear regression models, establishing that high wind power loads in west Texas cause interconnection congestion and electricity price differences with the remaining zones. The RES-E influence on interconnection congestion was also analysed by Ref. [34] for Sicily and the rest of Italy electricity prices, through the use of a time-varying regime switching models and a dynamic probit ruling the transition between regimes, with distinct results as wind power is found to decrease interconnection congestion, which according to the author may be due to wind curtailment practices by the TSO (Transmission System Operator). Moreover, Italy was studied by Ref. [35] through the use of multinomial logit and three stage least square models, reporting that the probability of interconnection congestion increases with high wind power generation exiting a bidding area and decreases with high wind power generation in the destination bidding area. For Iberia, [36] through a non-parametric approach, found that increasing wind power generation, or furthermore, increasing low marginal cost generation has a clear influence on market splitting, increasing its probability.

Therefore, this research aims to assess the influence of high availability of wind power on the market splitting behaviour of the Danish bidding areas in the Nord Pool electricity spot market, taking into account cross-border electricity flows. The leading hypothesis considered in this study is that, in spite of the multiple existing interconnections and associated cross-border flows, wind power generation still influences market splitting in Denmark.

Following [36], expanded to a new multi-interconnected electricity market, logit and non-parametric models are herein used to express the probability response for market splitting of day-ahead spot electricity prices as a function of wind power generation share, electricity demand interconnection cross-border flows and market splitting of adjacent bidding areas. Logit models contribute with preliminary indications on market splitting behaviour, in spite of the known specification limitations. These limitations are subsequently overcome with the use of non-parametric models as demonstrated in Ref. [36].

The structure of the paper is the following: in Section 2 the Danish electricity market characterisation is presented, consisting of a survey of the EU legislative framework and Danish energy policy, an overview of the renewables deployment in Denmark and a brief explanation of the Danish electricity market as part of the Nordic electricity market. Data and model specification used in this study are presented in Section 3, followed by the presentation of the model results in Section 4 and the respective analysis and discussion in Section 5. Section 6 concludes with some recommendations and policy implications.

2. Danish electricity market characterisation

2.1. EU and the Danish energy policy

The absence of energy natural resources together with the oil crisis of the 1970's drove Denmark into a path of extensive efforts in R&D (Research and Development) of endogenous energy sources. Within the period until 1990, Denmark developed oil and natural gas production in the North Sea, decreasing its dependency on oil imports. Additionally, energy security of supply was achieved by replacing oil consumption by coal and natural gas, and on the demand side by implementing a challenging energy saving programme [37,38].

Bearing in mind that oil and gas resources are scarce and following the Kyoto accords to reduce CO_2 emissions, Danish energy policy turned into the development of renewable energy sources. Nonetheless, the formerly existing Danish energy policy was deemed to be insufficient to achieve the established target of 20% CO_2 emissions reduction by 2005 compared with 1988, which created the need for the so called "Green Energy Plan", instigating the official "Energy 21" adopted in 1996. This plan comprised of the following measures: switching from electric heating to central heating, improving insulation and low-temperature district heating, utilisation of natural gas in district heating, diffusing the use of biomass, deployment of wind turbines (3000 MW by 2015), further stakeholder training and energy conservation [39]. These measures intended to attain the main objective of CO_2 reduction by also setting the following sub-targets: 20% improvement of energy conservation compared with 1994 and 12%–14% share of electricity consumption generated from renewable sources. Additionally, the chief goal of achieving 50% CO_2 reduction by 2030 compared with 1998, would be accomplished by increasing energy conservation to 55% above 1994 levels and 35% share of electricity consumption generated from renewable sources [37].

In 2005, the "Energy Strategy 2025" established the vision of total independence from fossil fuels. Targets were established to achieve a reduction of 15% for fossil fuel usage and keep a static overall energy consumption. Further specific targets were set for energy efficiency (1.25% annual growth), renewable energy (30% renewable energy share consumption by 2025) and more efficient new energy technologies (R&D support of new energy