Energy 114 (2016) 188–200

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Weather and market specificities in the regional transmission of renewable energy price effects

Nuno Carvalho Figueiredo [a, b, *], Patrícia Pereira da Silva [b, c], Derek Bunn [d]

[a] EFS Initiative, University of Coimbra, Sustainable Energy Systems – MIT-P, Coimbra, Portugal
[b] INESCC, Coimbra, Portugal
[c] Faculty of Economics, University of Coimbra, Coimbra, Portugal
[d] Department of Management Science and Operations, London Business School, Regent's Park, London NW1 4SA, UK

ARTICLE INFO

Article history:
Received 16 April 2016
Received in revised form
11 July 2016
Accepted 30 July 2016

Keywords:
Electricity
Market integration
Wind energy
Weather
Prices

ABSTRACT

This study is motivated by the observation that the effects of renewable energy output variations across several integrated power markets are likely to be complicated by price arbitrage and weather dynamics. Wind in particular has supply side effects when associated with substantial generating facilities, but also demand side influences when associated with extreme weather conditions. To unravel these effects, daily electricity prices and the weather variables wind, temperature and their interaction (wind chill) in the Central-West Europe coupled market were analysed from 2007 to the end of 2014 by means of vector autoregressions. The spillover effects were found to be quite subtle. Despite efficient price arbitrage, it is not the case that daily wind output shocks diffuse uniformly across all markets, or that the largest generator of wind energy creates the most significant spillovers or that high wind conditions necessarily lead to lower prices. Market specificities matter and are important for operational prediction and weather risk hedging.

1. Motivation

European policy to increase market integration in wholesale electricity trading has been intensively pursued since the vision of a single energy market emerged in the 1990s. Whilst the need for more interconnectors and harmonisation of trading was initially motivated by the pursuit of economic efficiency and greater competition, policy-makers have been encouraged further in this direction by the emergence of substantial amounts intermittent renewable generation. The rapid rise in generation from wind and solar in particular, again motivated primarily by policy, raises concerns about security of supply in the longer term and also efficient system balancing in the short term, both of which appear to be remedied to some extent by more regional interconnectivity. Moreover, with the renewable energy sources (RES) capacity forecast to grow substantially, ENTSO-E (2015) [1] emphasise the growing importance of cross-border electricity flows in order to maintain generation adequacy. In this context, therefore, it is easy to understand why there has been extensive research on modelling the progress of market integration in electricity prices, expressed both in terms of price convergence and the dynamics of shock transmissions.

However, the inter-regional price effects of large volumes of renewable energy are awkward to clarify, and the impact of weather has generally been under-specified in the market integration studies. Large volumes of renewable energy are weather induced, and their local price effects might transmit to neighbouring markets, arbitrage permitting, but weather conditions are also correlated across regions. Thus, even without interconnections, common weather conditions induce price co-movements. Furthermore, weather affects both the demand and supply sides of the markets in different ways and these will be idiosyncratic to the consumption drivers and generation technology mixes in each market. Unravelling these confounding factors is particularly important for system operations and price risk management. For example, the use of weather insurance, derivatives or other hedges require explicit models of price transmission between regions that distinguishes arbitrage effects from weather spillovers.

The objective of this paper is therefore to undertake a detailed econometric analysis of price transmission in the daily coupled

* Corresponding author. EFS Initiative, University of Coimbra, Sustainable Energy Systems – MIT-P, Coimbra, Portugal.
E-mail address: nuno.figueiredo@portugen.com (N.C. Figueiredo).

http://dx.doi.org/10.1016/j.energy.2016.07.157
0360-5442/

wholesale market of Central-West Europe (CWE) taking explicit account of renewable energy generation and with a focus upon the particular weather variables wind, temperature and their interaction (wind chill). The next section provides a review of relevant background research, followed by summaries of the European Union initiatives for market integration, renewable energies and the emergence of the CWE market. The data and analysis follow. On the basis of results from some large vector-autoregression models in section, we offer some new insights.

2. Background research

Weather conditions are essential variables for demand forecasting and numerous methods have developed over many years to model ambient temperatures in various forms, wind speed with its associated wind chill effects, humidity, cloud coverage and others. Maximum and minimum ambient temperatures were used for demand forecasting in Italy by Sforna (1995) [2], whilst Islam et al. (1995) [3] in Muscat used selected climate variables according to their correlation with electricity demand (maximum temperature, maximum and average relative humidity, wind speed, duration of sunshine, global radiation, degree days and a comfort index). Correlation of electricity demand and climate variables was also used to select adequate input variables by Santos et al. (2007) [4] and Amjady and Keynia (2009) [5]. Robinson (1997) [6] simply used a daily average ambient temperature in demand forecasting. Sailor and Muñoz (1997) [7] used in addition to ambient temperature, relative humidity (in the form of enthalpy latent days) and wind speed, all population-weighted. Taylor (2003) [8] improved on the existing use by the UK National Grid of single point weather forecasts, by using weather ensembles. A population-weighted mean daily outdoor temperature was used by Pardo et al. (2002) [9] to calculate heating and cooling degree days (HDDs and CDDs) for a demand model to account for the influence of temperatures on demand. The use of HDD, CDD and the mean relative humidity was also used by Mirasgedis et al. (2006) [10] in statistical models for the daily and monthly electricity demand prediction for Greece. Bessec and Fouquau (2008) [11] assessed the influence of temperature on demand across Europe and found a non-linear relation with a clear heating effect. Moreover, the cooling effect was more important in the south European countries with a clear U-shape relation. Suganthi and Samuel (2012) [12] performed a comprehensive review of the types of models used for demand forecasting, most of them involving climate conditions as explanatory variables. A study of climate determinants on demand was carried out for Italy [13] highlighting the importance of the increasing installation of air conditioning in the electricity demand since 2003.

To the extent that price forecasts depend upon demand, all of these weather effects pass through implicitly [14,15]. The introduction of weather determinants on electricity price forecasting is explicitly mentioned by many researchers [16,17]. However, Wu and Shahidehpour (2010) [18] suggest that weather variables might cause overfitting and model inaccuracies. Nevertheless, Weron and Misiorek (2008) [19] used ambient temperatures in the electricity price forecasting model for Nord Pool. Comprehensive reviews of electricity spot price modelling are made by Higgs (2008) [20], Aggarwal et al. (2009) [21] and by Weron (2014) [22], which report the use of ambient temperature as an input variable. Furthermore, Higgs and Worthington (2008) [23], Christensen et al. (2012) [24] and Zachmann (2013) [25] recognise that, in their multi-state models, the transition probabilities and electricity price spikes are, or may be, weather dependent. Wind power forecasts are used in electricity price forecasting by Cruz et al. (2011) [26], Jónsson et al. (2013) [27] and Ziel et al. (2015) [28] with appealing results, demonstrating model performance improvements. The latter also included solar power in the electricity price forecasting of Germany and Austria. Additionally, Keles et al. (2013) [29] introduces a self-contained wind power forecast, which is then used in the electricity price forecast. A summary of the analysed literature involving weather variables is provided in Table 6 Appendix A.

Regarding the interconnection of regional electricity markets, De Vany & Walls (1999) [30] looked at market integration across eleven regions in the western United States using spot market electricity prices from 1994 to 1996, aggregated by peak and off-peak values, as did Park, Mjelde, & Bessler (2006) [31]. In Australia, Worthington, Kay-Spratley & Higgs (2005) [32] examined the integration of the Australian National Electricity Market, but found poor integration. Later, Higgs (2009) [33] also assessed the Australian National Electricity Market in terms of the level of integration, examining the inter-relationships of wholesale spot electricity prices among four markets, finding by then that the highly interconnected markets have higher conditional correlations. In Europe several studies have looked at market integration (e.g. Refs. [34,35]). Econometric methods have been based upon on correlations, cointegration analysis, fractional cointegration, exploratory data analysis of price differences variability, vector autoregressive (VAR), vector error correction models (VECM), Granger-causality, principal components and impulse response analyses. The Central-West Europe (CWE) region was found to be integrated in these studies and increasingly so over time. Lately the authors specified a number of VAR models to evaluate the effects of the introduction of the market coupling mechanism between the trilateral market (Belgium, France and the Netherlands) and Germany, leading to the conclusion that this has created an apparent smoothing of the responses to innovations of the integrated CWE markets [35].

3. Market integration, renewable energies and the CWE

Directive 90/547/EEC on the transit of electricity through transmission grids [36] aligned to Directive 90/377/EEC concerning the transparency of gas and electricity prices charged to industrial end-users [37], provided the first steps for the creation of the internal European electricity market. Later, Directives 96/92/EC, 2003/54/EC and 2009/72/EC established harmonised rules for the various electricity markets [38,39]. Regulatory agencies were created throughout the European Member States in order to transpose and implement the local corresponding laws and regulations. The main regulatory functions aimed to: provide licencing, perform monitoring of activities, set and implement tariffs, and to protect customers [40]. In 2006, market integration in Europe was still far from being achieved [41], and this led the European Commission to foster an Agency for the Cooperation of Energy Regulators (ACER) which in turn launched seven Electricity Regional

Table 1
Indicative values for NTC in MW.

To	From				
	BE	DE	FR	LU	NL
BE [19,500][a]			3400		2400
DE [163,800][a]			2700		3000
FR [125,900][a]	2300	3200			
LU [1800][a]		980			
NL [28,200][a]	2400	3850			

[a] Installed Electricity Generation Capacity in MW [45].