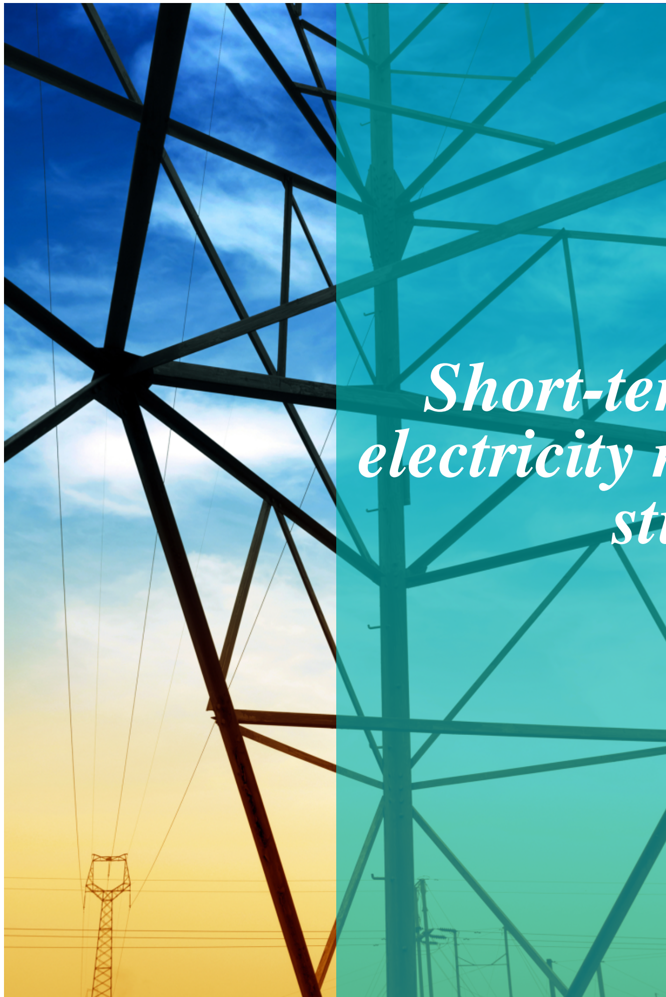

Short-term dynamics in day-ahead and intraday electricity markets with rising wind power – two case studies of Denmark and Nord Pool

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Outline

Nord Pool Spot

Elspot: day-ahead market; trading more than 80% of all power.

- Transmission constraints: various bidding areas.
- System price and area price: available transmission capacities may vary and congest the flow of electricity between the bidding areas.
- Market coupling: Germany and the Netherlands

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- Continuous market
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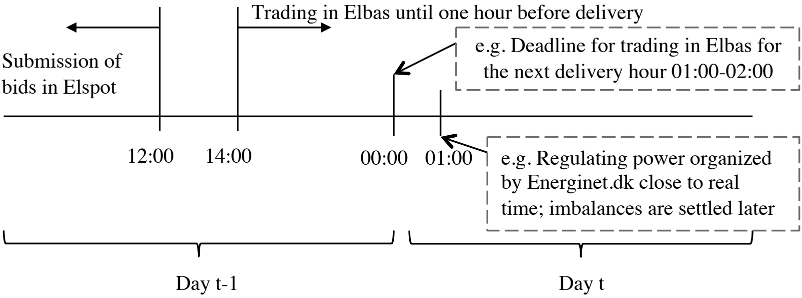
Balancing market

- Regulating power: TSOs buys and sells through BRPs
- Balancing power: financial neutralization for imbalances after delivery

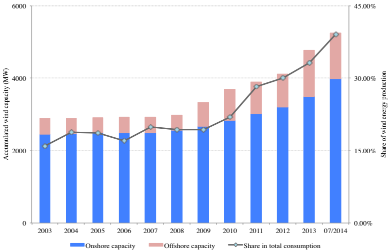
Figure 1 : Timeline of the Nordic sequential electricity trading



Wind power generation in Denmark

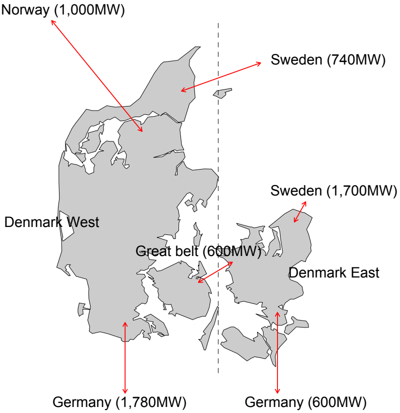
- Domestic combined heat and power (CHP) and hydropower in neighbouring countries
- Elspot: remuneration was made up of the market price plus a premium since 2004
- Wind generators: Balancing Responsible Parties (BRP)
- Target: 50% wind energy in consumption by 2020; 100% by 2050

Accumulated wind capacity and share in total electricity consumption



Data source: Authors' realization based on Danish Wind Industry Association (2014) and Danish Energy Agency (DEA) (2015).

Figure 2 : Cross-border connections and transmission capacities between Denmark and neighboring countries



Data source: Author's realization based on energinet.dk (2015). Western Denmark is connected to Norway, Sweden and Germany. Eastern Denmark is connected to Sweden and Germany.

Outline

Background

The topics

Elspot and wind power

Elbas and wind power

Implications, caveats and future work

Research topics

1. Short-term price and volatility dynamics, and forecasting in day-ahead electricity markets with rising wind power.

2. A novel idea to test the functionality of an intraday market and how wind power is integrated (joint with Fatih Karanfil).

Outline

Features of the study

Short-term price and volatility dynamics in the Elspot day-ahead market

- Market fundamentals: wind power, market coupling, Danish imports
- Idiosyncrasies of electricity prices: seasonality, asymmetric impacts of innovations (inverse leverage effect (Knittel and Robert, 2005)), heavy tails
- Hourly data for the period of March 25, 2012 to March 24, 2015

Market drivers

- Wind power: merit order; effect on short-term volatility less clear
- Market coupling with Germany and the Netherlands
- Exchange with available hydropower in Norway and Sweden: the Danish strategy to handle Intermittency (Green and Vasilakos, 2012)
  - Exporting when wind penetration is high and hydro is low
  - Importing when wind penetration is low and hydro is high

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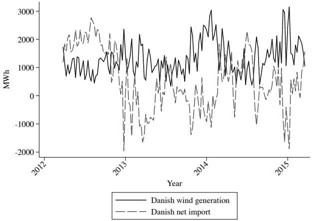
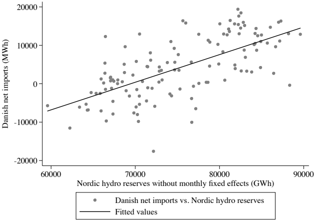


(a) Danish wind and net imports



(b) Net imports and Nordic hydro storage

Figure 3 : Correlations between Danish wind generation, Danish net imports and Nordic hydro storage

Idiosyncrasies of the day-ahead price

Complexity of electricity spot prices: seasonality at multiple levels, serial correlations, mean reverting, spikes, skewness and heavy tails.

→ *Carefully treating long- and short-term seasonality can produce superior estimation and prediction results (Janczura et al., 2013).*

$$P_t = \underbrace{f_t}_{\text{Deterministic part: LTSC and STSC}} + \underbrace{p_t}_{\text{Price without seasonality}} \tag{1}$$

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Three-step approach (Weron, 2009; Janczura and Weron, 2010)

1. LTSC: wavelet decomposition and smoothing
2. STSC: weekly median
3. Scaling up by hourly means

Wavelet decomposition and smoothing

Any signal can be decomposed into one father wavelet and a sequence of mother wavelets: $f(t) = S_J + \sum D_j$; Choosing $J = 6$ $\Rightarrow$ Bimonthly smoothing

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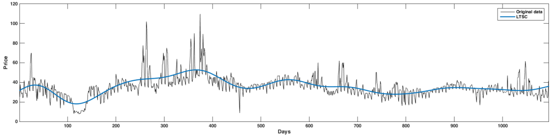
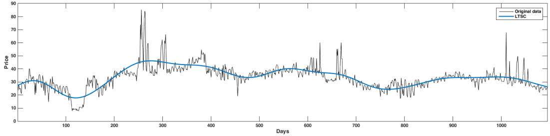
Figure 4 : Estimation of the LTSC

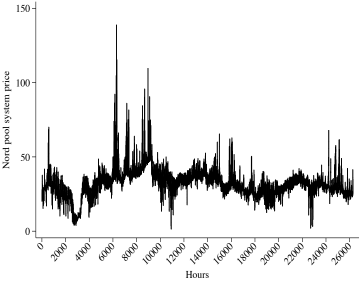


8am-9am



4pm-5pm

Hourly day-ahead spot price and deseasonalized price in Elspot (€/MWh).



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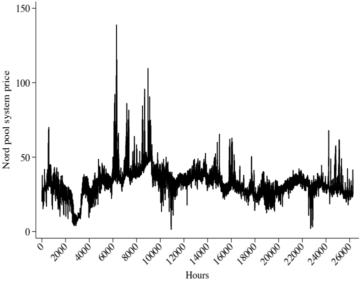

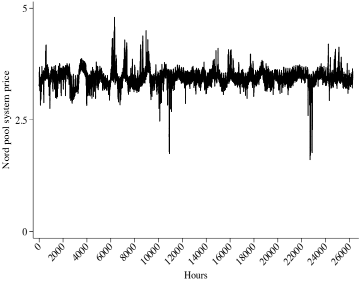

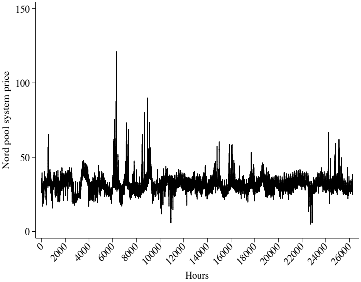

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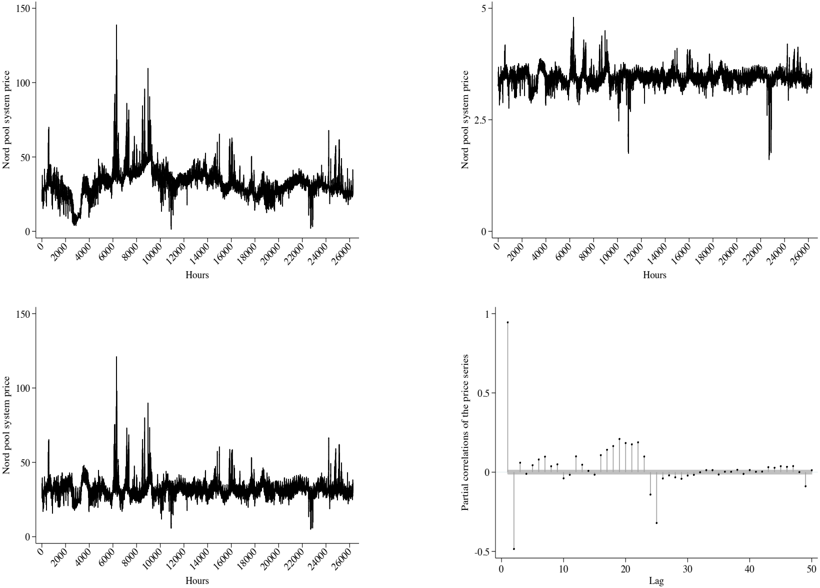

Estimation strategy

- AR-GARCH with exogenous variables
- Asymmetric GARCH: EGARCH, TGARCH, GJRGARCH
- Heavy tails: Student's t distribution
- Model fits: AIC and BIC
- Forecast performance: RMSE, MAE, MAPE and TIC

Empirical results

Table 1 : Estimation results of asymmetric GARCH compared with GARCH

Mean Equation	GARCH	EGARCH	TGARCH	GJRGARCH
δ	3.116***	3.575***	3.432***	-0.012
log(Wind)	-0.010***	-0.010***	-0.010***	-0.011***
Net coupling	-7.69e-06***	-7.07e-06***	-7.11e-06***	7.16e-06***
Net import	2.63e-06***	3.44e-06***	3.25e-06***	2.27e-05***
log(Load)	0.036***	0.009	0.023***	0.339***
AR(1)	1.206***	1.254***	1.247***	0.521***
Variance Equation				
ω	0	-0.776***	0.005***	0.004***
α	0.696***	0.415***	0.233***	0.275***
β	0.302***	0.930***	0.782***	0.641***
γ		-0.042***	0.098***	0.164***
log(Wind)	-6.37e-05***	-0.046***	-0.001***	-1.27e-04***
Net coupling	-5.76e-08***	-4.56e-05***	-5.92e-07***	-9.93e-08***
Net import	-5.14e-08***	-4.96e-05***	-6.23e-07***	-9.91e-08***
log(Load)	7.57e-05***	0.028***	8.62E-05	-2.51e-04***
R2	0.94	0.94	0.94	0.9
Adj. R2	0.94	0.94	0.94	0.9
LL	54330	54484	54401	47800
AIC	-4.14	-4.15	-4.14	-3.64
BIC	-4.13	-4.14	-4.13	-3.63
ARCH test	0.16	0	0	0

Empirical results

Table 2 : Estimation results under Student's t distribution

Mean Equation	**GARCH**	**EGARCH**	**TGARCH**	**GJRGARCH**
δ	1.208***	1.159***	1.138***	-0.002
log(Wind)	-0.008***	-0.008***	-0.008***	-0.014***
Coupling	-9.95e-06***	-9.76e-06***	-9.84e-06***	-4.94e-06***
Import	3.45e-06***	3.66e-06***	3.62e-06***	9.33e-06***
log(Load)	0.203***	0.207***	0.209***	0.330***
AR(1)	1.295***	1.295***	1.290***	0.352***
Variance Equation				
ω	0.003***	-0.248	0.056***	0.011***
α	1.056***	0.903***	0.645***	0.239***
β	0.182***	0.613***	0.271***	0.510***
γ		-0.024*	0.044**	0.105***
v	2.692***	2.667***	2.671***	20.000***
log(Wind)	-2.65E-06	-0.021**	-1.58E-04	-2.53e-04***
Coupling	-2.87e-08***	-4.04e-05***	-6.04e-07***	-1.54e-07***
Import	-3.88e-08**	-5.85e-05***	-8.40e-07***	-1.69e-07***
log(Load)	-2.41e-04***	-0.256***	-0.004***	-8.38e-04***
R2	0.94	0.94	0.94	0.88
Adjusted R2	0.94	0.94	0.94	0.88
LL	59085	58979	59076	48115
AIC	-4.50	-4.49	-4.50	-3.66
BIC	-4.49	-4.48	-4.49	-3.65
ARCH test	0.91	0.96	0.99	0

Forecast performance

Table 3 : Forecast evaluation of GARCH specifications under a Student's t distribution

	GARCH	EGARCH	TGARCH	GJRGARCH
RMSE	0.0645	0.0391	0.0392	0.1186
MAE	0.0478	0.0246	0.0246	0.0979
MAPE	1.3798	0.7076	0.7084	2.8497
TI	0.0094	0.0057	0.0057	0.0171

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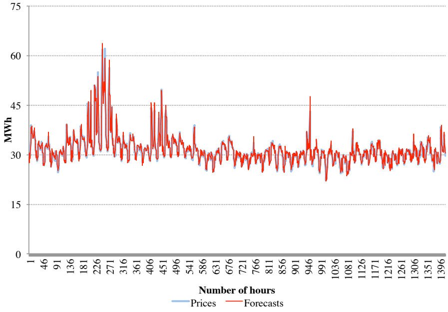
Figure 5 : Out-of-sample forecasts 25/01/2015-24/03/2015



Discussions and conclusions

- 1% increase in wind output $\Rightarrow$ 0.008% decrease in price
- Negative effect of market coupling and positive effect of net imports to reflect opportunity cost of hydro
- 1% increase in wind output $\Rightarrow$ 0.02% decrease in price variance
  - Price stabilizing effect jointly from market exchanges
  - Intraday volatility: long-term and short-term
  - Area prices are more volatile
- A standard "leverage effect" considering different asymmetric GARCH specifications
- Accounting for fat-tail error distributional property improve significantly model fits and forecast performance

Outline

Features of the study

This study is to answer:

1. How intraday prices deviate from the day-ahead ones and what fundamental drivers cause this deviation
2. How wind forecast errors are dissolved

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- First empirical study to test the functionality of the intraday market by causality tests using an example of the two Danish bidding zones
- Causality links among fundamentals of the price differences: wind, conventional generation, consumption forecast errors, power trades.
- Persistency and durations of price and quantity divergences

Economic rationale

- Intraday trading allows participants to modify day-ahead quantities; important tools to deal with intermittent wind power
- Liquidity issues in intraday markets (Weber, 2010; Hagemann and Weber, 2013; Furió et al., 2009)
- An ideal intraday mechanism should not be targeting at a high trading volume *per se* (Henriot, 2014)
- Nord Pool: abundant hydro reserves could dampen the interest of close-to-real-time trades

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A new perspective

Intraday price signals and other market drivers can effectively respond to wind forecast errors if Granger causalities are found.

Methodology

Test of stationarity
All series
are stationary → Vector autoregressive (VAR) model
→ Generalized impulse response (GIR) analysis

Empirical results

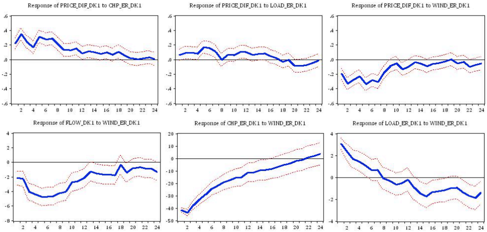
- Wind and conventional power forecast errors → intraday price deviations from the day-ahead prices
- Demand deviations in DK1; cross-border trading in DK2
- Wind forecast errors affect significantly CHP forecast errors, load forecast errors, and intraday cross-border trades

Table 4 : Results of Granger causality

	Dep. Var.	Price_dif	Wind_er	CHP_er	Load_er	Flow
DK1	Price_dif	-	92.17**	57.57**	45.99*	36.49
	CHP_er	38.71	330.5**	-	27.85	94.91**
	Load_er	57.71**	57.31**	60.25**	-	32.5
	Flow	33.23	123.6**	108.4**	24.11	-
DK2	Price_dif	-	62.12**	106.6**	24.06	47.10**
	CHP_er	45.85**	121.0**	-	157.8**	76.25**
	Load_er	40.30*	85.14**	156.1**	-	29.07
	Flow	56.02**	113.75**	78.02**	24.23**	-

Empirical results

Figure 6 : Responses in DK1 to generalized one standard deviation innovations ± 2 standard errors.



- Merit order: wind forecast errors decrease intraday price divergences while CHP errors do the opposite
- Negative shocks to wind output stimulate power imports in the intraday market and vice versa
- Duration of divergences in the Elbas intraday market: 12 hours
- CHP power generation is adjusted in the opposite direction and consumption is adjusted in the same direction.

Conclusions

- Zonal differences concerning additional causalities to price differences and fundamentals response paths

Conclusions

- Wind and conventional generation forecast errors are the fundamental factors to intraday price deviations.
- Wind forecast errors are found to be absorbed by joint responses from other fundamentals.
- Zonal differences concerning additional causalities to price differences and fundamentals response paths
- Confirmed the effective functioning of the intraday market in the case of Denmark

Outline

Implications, caveats and future research

Importance of interactions between wind power and hydropower, and market integration.

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Future work:

- Investigation of area price volatility and volatility in different time horizons: the extent of constraint on transmission
- Overall system efficiency: cost and price comparisons between intraday trading and real time balancing subject to transmission capacities
- Strategic behaviours of wind generators

Thank you!