Wind Park Valuation and Risk Management in German Intraday Power Markets

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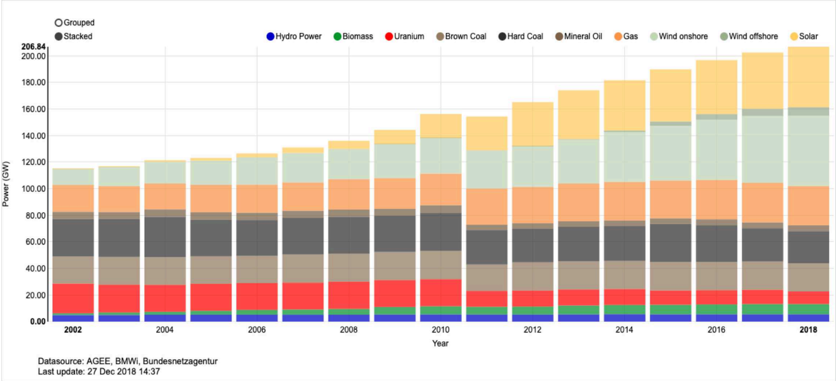
Mix of Generation Capacity in Germany, 2002-18

Rapid growth of installed renewable capacity in Germany recently...



Capacity more than 50% now, though generation still less than half.

(note: plot taken from www.energy-charts.de)

Wind Park Valuation and Risk Management

Common contractual arrangement (for every quarter hour T):

- Wind park owners pay a manager to take control of selling production.
- Owners recieve day-ahead price minus a premium p paid to manager.
- Manager can sell on day-ahead or intra-day, adjusts position given forecast changes, and faces a possible penalty for imbalances at T.

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- Finding a manager's trading strategy to minimize intraday rebalancing costs as well as the risk of high penalties at delivery time T!
- Potential extension to wind parks coupled with a battery and possibly biomass unit? (for time-shifting of power and imbalance mediation)

Related Literature

- Growing interest in academia and industry on intraday electricity price dynamics *(e.g. Kramer & Kiesel; Kiesel & Paraschiv; Graf von Lucknow & Kiesel; Uniejeweski, Marcjasz & Weron)*
- Some work on trading strategies in intraday markets *(e.g. Pham, Gruet & Aïd; Edoli, Fiorenzani & Vargolu)*
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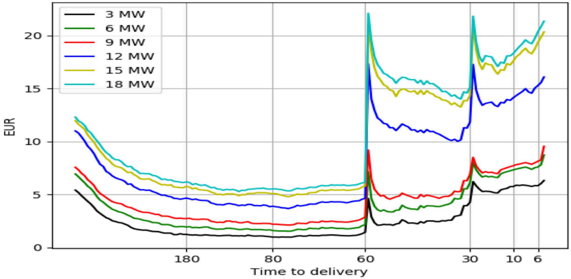
- Park level variations in forecasts, actual generation and correlations
- Large differences in order book dynamics over time (vs t, T and $T-t$)
- Variety of imbalance penalty regimes and corresponding incentives

Can Trade in Various German Intraday Power Markets...

- Day-ahead auction (at 12pm; hourly contracts)
- Intraday auction (at 3pm; quarter-hour contracts)
- XBID intraday trading (6pm until 1 hr before delivery T)
- EPEX intraday trading (until 30 min before T)
- TSO-level intraday trading (until 5 min before T)



Median bid-ask spread at different volumes as t approaches T

Price Related Notation

Letting $p_t(T, T', v)$ denote the price of a volume v delivered between times T and T' (either 15 min or 1 hour later), we are interested in mid prices $m_t(T, T')$ and bid-ask spreads $s_t(T, T', v)$:

$$m_t(T, T') = \frac{p_t(T, T', 0) + p_t(T, T', 0)}{2}$$
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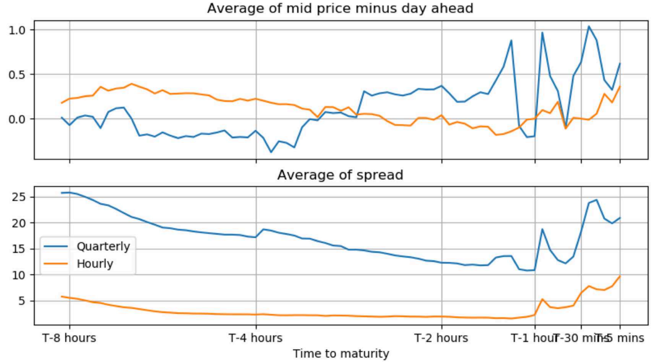
Spread dynamics clearly change as T approaches, and also have a shape versus v, as implied by the previous figure. Thus, let

$$s_t(T, T', v) = r_t(T, T')h(T - t, v)$$

where $r_t(T, T')$ is a stochastic process, and $h(T - t, v)$ a function monotone in v (capturing the 'shape' of the order book).

Behaviour of mid-prices and spreads versus $T - t$

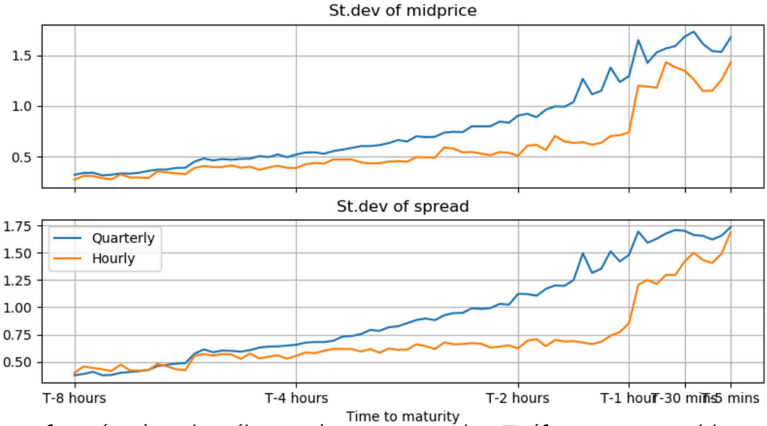
Introduction of XBID in mid-2018 created new cross-border trading opportunities and tighter bid-ask spreads, esp. near $T - 1/24$ (60 min) $\implies$ less costly rebalancing for wind farm operators!



Mean of m_t (top) and s_t (bottom) as t approaches T (for quarters and hours)

Behaviour of mid-prices and spreads versus $T - t$

Looking at standard deviations instead of means, we see steady increase in vol as maturity approaches (i.e. more trading, wind forecast updates)...



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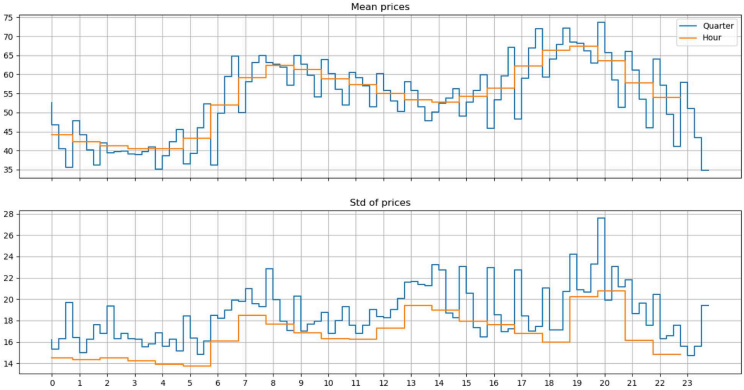
Intraday Market: Hourly and Quarterly Contracts

24 hourly contracts and 96 quarterly contracts trade for each calendar day. Intraday patterns are prominent and linked to generator ramping patterns.

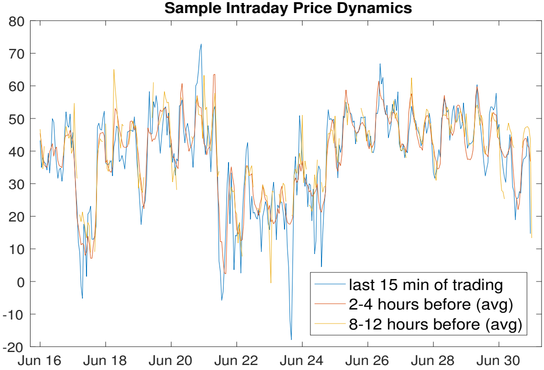


Mean price by hour and quarter (top) and standard deviation (bottom)

Intra-day Price Behaviour

Sample price data for a sequence of contracts T (and three $T-t$) reveals:

- Prominent daily periodicities, occasional spikes and negative prices
- Heavier tailed distributions and higher volatility for smaller $T-t$



Volume weighted average intraday prices, late June 2018

Problem Formulation - Wind Park Manager

Recall: Managing a wind park in isolation (no battery, etc.), for each hour/quarter (T, T'), the manager aims to maximize cashflows $C(T, T')$ by optimally selling the forecasted production day-ahead (DA) or intra-day:

$$C(T, T') = \tilde{v}_{t_{DA}} P_{t_{DA}} + \sum_{u \in \mathcal{U}} v_u (m_u + s_u(v_u)) + (f_T - \tilde{v}_{t_{DA}} - \sum_{u \in \mathcal{U}} v_u) R$$

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with (dropping T and T' from all notation for simplicity)

- $\mathcal{U} = \{t_{DA} < u_0 < u_1, u_2, \ldots < T\}$ a sequence of trade times,
- R the terminal imbalance penalty (called 'REBAP'), which is very heavy-tailed and also correlated with prices m and German wind,
- $\tilde{v}_{t_{DA}}$ the volume sold on day-ahead (at price $P_{t_{DA}}$),
- v_u a sequence of intra-day volumes (sold if $v > 0$, bought if $v < 0$),
- f_T the park's final generation at T (notation f_t for forecasts at $t < T$),
- and with mid-price and spread processes m and s as before.

Problem Formulation - Wind Park Manager

Given total future cashflows (P&L) for each delivery period as above

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at any t, the manager chooses a trading strategy $v_t\left(v_{0:t}, f_{0:t}, m_t, s_t\right)$ to maximize $\mathbb{E}_t[C(T,T')]$. With unbiased forecasts we might expect

$$v_t\left(q_t, m_t, s_t\right)$$

where $q_t = f_t - \tilde{v}_{t_{DA}} - \sum_{u<t} v_u$ is the current forecasted imbalance

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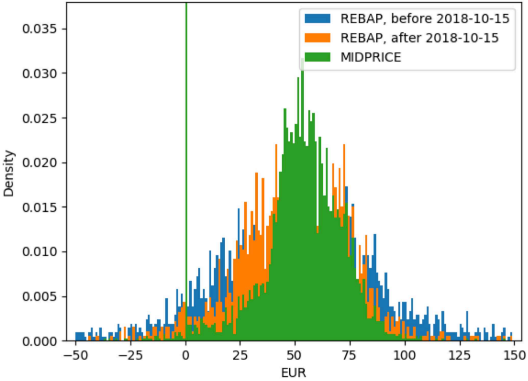
HOWEVER: Is this objective realistic?! And how does R really work?

- In Germany, penalty term $(f_T - \tilde{v}_{t_{DA}} - \sum_{u \in \mathcal{U}} v_u)R$ can also be in your favour (esp. for 'low correlation' parks), complicating matters.
- But managers are risk-averse (and R very risky), so mean-variance?

REBAP Data - Distribution of R vs m

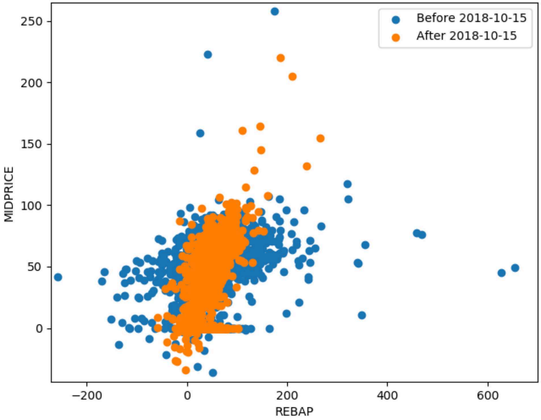
R has mean 2 euros lower and is much wider than m (but less so recently).
(Note: plot below truncated: values near 1000 or -500 also observed)



Histogram of midprice m_t (at $T - 1/24$) and R distributions pre and post Oct 2018.

REBAP Data - Correlation between R and m

Clear correlation, and a change in the behaviour of R since Oct 2018...



Scatter plot of m_t (at $T - 1/24$) versus R, pre and post 2018.

Related Problem - Wind Park Valuation

A closely linked problem is to find a park's fair premium p, since the full cashflows of the manager for each delivery period include paying the owner spot (day-ahead) minus p for all production:

$$\tilde{C}(T,T') = C(T,T') - f_T\left(P_{t_{DA}} - p\right)$$

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We study many different wind parks with various characteristics:

- How does a park's correlation with national wind (thus m_t) impact p?
- What about forecast reliability (or bias) and variability over t?
- As before, what trading / hedging strategy is best? (e.g. take high bid-ask spreads early vs risk penalties later; level of risk aversion?)

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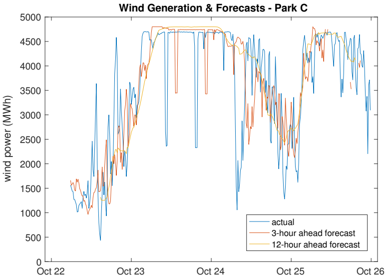
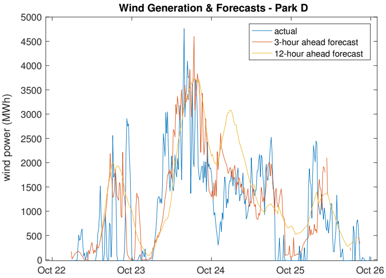
Next question: What does $f_t(T)$ look like for different parks?

Sample Wind Park Data

Wind power is highly volatile, with a wide variety of observable behaviour (e.g. seasonal patterns, spikes, upper/lower bounds, links to forecasts):

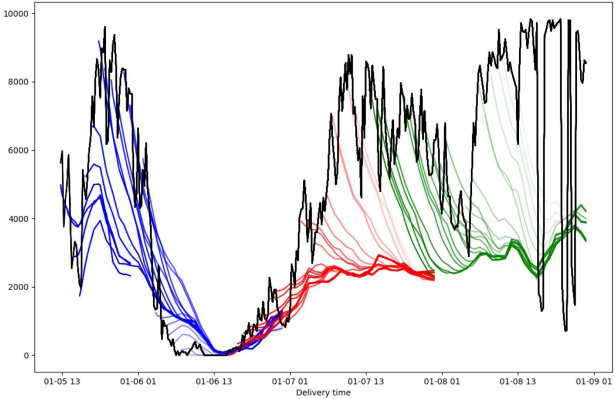




Oct 2018: a 4-day sample of generation, 3 and 12 hour forecasts for two German parks

Sample Wind Park Data

At park level clear evidence of forecasts simply reacting to recent actuals...

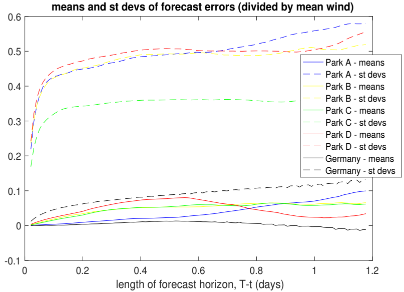


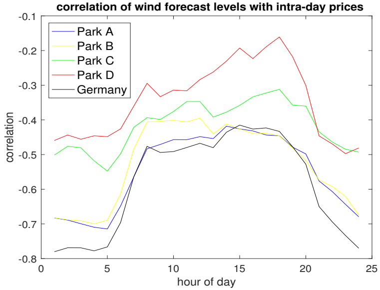
Sample of three days of actuals (black) and forecasts (colours)

Sample Wind Park Data

Features of wind forecast data include:

- Noticeable forecast bias (overestimation) for parks but not nationally.
- High volatility of parks forecasts near T but not as much nationally.
- Range of correlations with national wind and hence with intraday prices (Parks A to D from strongest to weakest).





Means and st devs of forecast errors (left); wind to price correlations (right)

Wind Park Valuation - Naive Initial Strategy

Consider R as final intraday price P_t, and assume strong incentive to always avoiding imbalances at T. Then a simple (very risk-averse) strategy:

- Sell full day-ahead forecast in day-ahead market ($t_0 = t_{DA}$ here)
- Rebalance ASAP as forecasts move (can cap MWh traded each step)

$$\begin{aligned} \text{Then } C(T) &= f_{t_0} P_{t_0} + \sum_{i=1}^{N} P_{t_i} \left(f_{t_i} - f_{t_{i-1}} \right) - f_{t_N} \left(P_{t_0} - p \right), \\ \text{where } t_0 &\approx T - 1 \text{ (day-ahead), and } t_N \approx T \text{ (last trade)} \end{aligned}$$

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$$\text{where } t_0 \approx T - 1 \text{ (day-ahead), and } t_N \approx T \text{ (last trade)}$$

Taking expectations, summing over all hours, setting to zero and solving for a 'fair' p (e.g. the lowest a manager might accept / bid for?):

$$p = \frac{\sum_T \mathbb{E}\left[P_{t_0} \left(f_{t_0} - f_{t_N} \right) | t_0 \right]}{\sum_T \mathbb{E}[f_{t_N} | t_0]} + \frac{\sum_T \mathbb{E}\left[\sum_i^N P_{t_i} \left(f_{t_i} - f_{t_{i-1}} \right) | t_0 \right]}{\sum_T \mathbb{E}[f_{t_N} | t_0]}$$

If forecasts are unbiased ($\mathbb{E}[f_{t_N} | t_0] = f_{t_0}$), then first term goes to zero!

Initial Tests

Although highly simplistic (no price model, and not capturing key trade-off of illiquidity vs risk of waiting too long to rebalance), we can gain insight from historical back-tests of the naive strategy above for different parks:

	premium p	correlation with Ger F_t	DA forecast bias (KWh)	DA forecast bias (%)	avg forecast vol near T
Park A	0.104	0.894	260.4	6.02	0.115
Park B	0.159	0.883	114.8	3.41	0.122
Park C	0.258	0.780	38.5	1.97	0.087
Park D	-0.025	0.599	145.2	9.32	0.125

Results provide some intuition about main pricing ideas:

- Weakly correlated parks are more valuable (e.g. negative premiums!)
- Evidence for forecast biases in some parks affects valuation

Improved naive strategies include for example waiting until imbalance reaches some shrinking barrier $B(T-t)$ away from fully balanced.

Returning to Original Problem - Price Modelling

We require a joint price and wind model. Starting with prices for k hourly products (we typically consider 8 at once), the data suggests a model

$$dm_t^h(T,T') = \Sigma^h(t,T)dW_t$$

where Σ^h is a k-dimensional function and dW is a k-dimensional B.M. The spread has a clear (decreasing) mean value μ_t^h in line with plot earlier. Let

$$dr_t(T,T') = \kappa(\mu_t^h - r_t)dt + \sqrt{r_t}\sigma(t,T)dB_t$$

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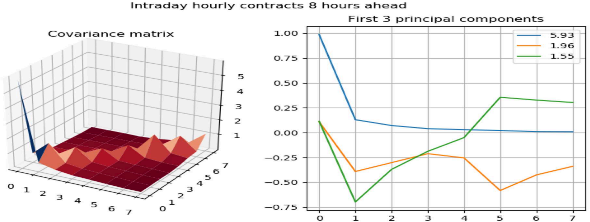
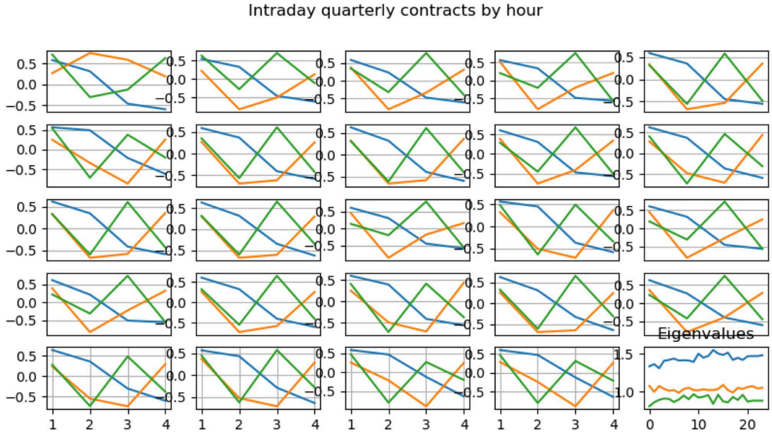
PCA results show classic term structure dynamics via dimension reduction:



Covariance matrix (left) and PCA results (right) for hourly mid-prices m_t^h

Quarterly Price Modelling

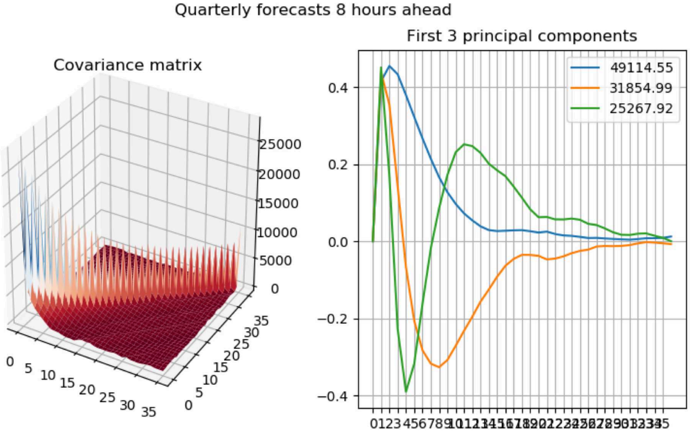
Extending from an hourly price model to quarterly, we see a fairly consistent 'term structure' effect between quarters across the 24 hours:



PCA results on quarters: 24 hourly results, with eigenvalues in bottom right

Wind Forecast Modelling

Similarly, PCA conveniently captures term structure in forecasts $f_t(T)$



Covariance matrix (left) and PCA results (right) for quarterly forecasts f_t

Additional Model Components

Various other pieces required to complete the full model:

- Estimating correlation structure between price and wind components
- Estimation of 'shape function' $h(v)$ for spreads (order book)
- Distribution for imbalance price/penalty R, correlation with m_T, f_T.

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- Distribution for imbalance price/penalty R, correlation with m_T, f_T.

We can then solve for the optimal trading strategy v_t at each time step given different choices of objective function (e.g. weighting of mean vs variance), and penalty regimes. Currently investigating / comparing

- Full dynamic programming approach (simplifying dimensionality)
- Approximate LP formulation choosing all future trades v_u for $u \in [t, T]$

Ideally need a computationally efficient approach for live trading decisions.

So where are we now?

- Model - parameter estimation close to completion and seems sensible
- Results - reasonable tests on simple strategies and historical paths
  - martingale-like data sugggests we cannot 'beat the market'
- Insights - links with correlations generally sensible, validating ideas
  - spread minimization vs REBAP threat is critical trade-off
- Next steps - computation of optimal strategies and comparing results
- Further aims - consideration of sequences of linked delivery periods, allowing for extension to case of battery / biomass combinations
- Conclusions - a little early to say! hopefully interesting ones soon! :)