# Trading wind energy based on probabilistic forecasts of wind generation and market quantities

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January 31, 2019

# What is the article about ?

#### Context

- Portfolio of wind energy (can be solar)
- Liberalized electricity markets

#### Goals

- Propose an operational trading strategy (based on the quantile of wind power production)
- Assess its performance

## Inputs of the model

#### Forecasts of

- Wind power production
- Spot market prices
- Imbalance prices (regulating market prices)

Remark: Not a forecasting problem!

# What are the main assumptions?

### Assumptions

- Price-taker
- No practical limitations
- Don't care about the risk: only the long run matters, ie we may face severe losses on the short run
- No curtailment
- PTU (Program Time Units) are independent: no market dynamic.
- Imbalance volumes are never rewarded

## **Notations**

#### **Notations**

- k: a specific PTU
- ullet  $W_k$ : amount of energy contracted in the spot market
- $W_k$ : stochastic production of wind energy
- $\rho_k$  : revenue
- $\rho_k^{(S)}$  : revenue from spot
- $ho_k^{\left(\uparrow/\downarrow\right)}$  : revenue from balancing
- $\pi_k^{(S)}$  : spot market price
- $\pi_k^{(\downarrow)}$  : down-regulation price
- $\pi_k^{(\uparrow)}$  : up-regulation price

# Some relations

#### Relations that hold

• 
$$\rho_k = \rho_k^{(S)} + \rho_k^{(\uparrow/\downarrow)}$$

$$\bullet \ \rho_k^{(S)} = \pi_k^{(S)} \widetilde{W}_k$$

• 
$$\pi_k^{(\downarrow)} \leq \pi_k^{(S)} \leq \pi_k^{(\uparrow)}$$

# Reformulating the revenue

#### Reformulating the revenue

• 
$$\rho_k = \pi_k^{(S)} W_k + C_k^{(\uparrow/\downarrow)}$$

$$\bullet \ C_k^{(\uparrow/\downarrow)} = \left\{ \begin{array}{l} \psi_k^{(\downarrow)} \left( W_k - \widetilde{W}_k \right), \quad W_k \ge \widetilde{W}_k \\ \psi_k^{(\uparrow)} \left( W_k - \widetilde{W}_k \right), \quad W_k < \widetilde{W}_k \end{array} \right.$$

- $\bullet \ \psi_k^{(\downarrow)} = \pi_k^{(\downarrow)} \pi_k^{(S)}$
- $\bullet \ \psi_k^{(\uparrow)} = \pi_k^{(\uparrow)} \pi_k^{(S)}$

# Idea

ullet revenue  $=\left( ext{term ind. from }\widetilde{W}_k
ight)+\left(\Delta ext{price }\cdot\Delta ext{imb. volumes}
ight)$ 

# Maximazing the revenue

## Expected Utility Maximization (EUM)

- We want to find  $\widetilde{W}_k = \operatorname*{arg\,max} \mathbb{E}\left\{ 
  ho_k \right\}$   $\widetilde{W}_k$
- ullet . . . which becomes  $\widetilde{W}_k = rg\max_{\overline{W}_k} \left\{ C_k^{(\uparrow/\downarrow)} 
  ight\}$

# Reformulating $C_k^{(\uparrow/\downarrow)}$

• 
$$\mathbb{E}\left\{C_{k}^{(\downarrow/\uparrow)}\right\} = \underbrace{\int_{0}^{+\infty} \int_{0}^{\widetilde{W}_{k}} \psi_{k}^{(\uparrow)} \left(W_{k} - \widetilde{W}_{k}\right) dP_{W_{k}} dP_{\psi_{k}^{(\uparrow)}}}_{\widetilde{W}_{k} \geq W_{k}: \text{ short position}} + \underbrace{\int_{-\infty}^{0} \int_{\widetilde{W}_{k}}^{W^{(max)}} \psi_{k}^{(\downarrow)} \left(W_{k} - \widetilde{W}_{k}\right) dP_{W_{k}} dP_{\psi_{k}^{(1)}}}_{\widetilde{W}_{k} < W_{k}: \text{ long position}}$$

# A stochastic optimization problem

## A stochastic optimization problem

- Idea: getting rid of  $\psi_k^{(\downarrow)}$  and  $\psi_k^{(\uparrow)}$
- $\mathbb{E}\left\{C_{k}^{(\downarrow\uparrow\uparrow)}\right\} = \widehat{\psi}_{k}^{(\uparrow)} \int_{0}^{W_{k}} \left(W_{k} \widetilde{W}_{k}\right) dP_{W_{k}} + \widehat{\psi}_{k}^{(\downarrow)} \int_{\widetilde{W}_{k}}^{W(max)} \left(W_{k} \widetilde{W}_{k}\right) dP_{W_{k}}$
- $\bullet$  ... where  $\hat{\psi}_k^{(\uparrow)} = \int_0^{+\infty} \psi_k^{(\uparrow)} dP_{\psi_k^{(\uparrow)}}$
- ... and  $\widehat{\psi}_k^{(\downarrow)} = \int_{-\infty}^0 \psi_k^{(\downarrow)} dP_{\psi_k^{(\downarrow)}}$

#### Remark

• Are  $\left\{\psi_{k,t}^{(\downarrow)}\right\}_t$  and  $\left\{\psi_{k,t}^{(\uparrow)}\right\}_t$  stationary ?

# Solution of the SOP

#### Solution

$$\bullet \ \widetilde{W}_k = F_{W_k}^{-1} \left( \frac{\left| \widehat{\psi}_k^{(\downarrow)} \right|}{\widehat{\psi}_k^{(\uparrow)} + \left| \widehat{\psi}_k^{(\downarrow)} \right|} \right)$$

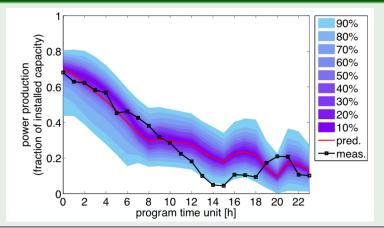
•  $F_{W_k}$  cumulative distribution function of  $W_k$ .

#### Remark

ullet A probabilistic forecast of  $W_k$  is needed

# Probabilistic forecast of $W_k$





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