



# Probabilistic Forecasting and Bidding Strategy of Ancillary Services for Aggregated Renewable Power Plants

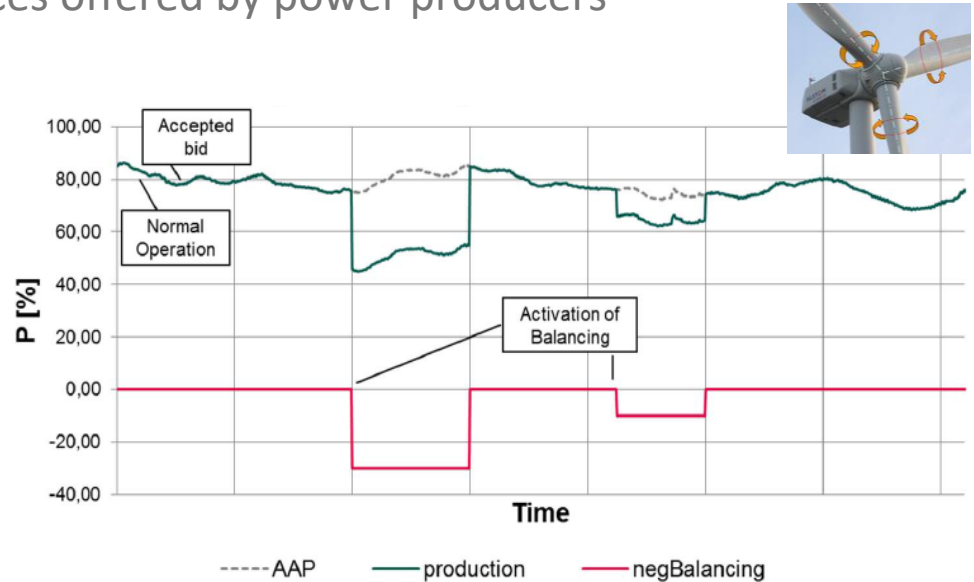
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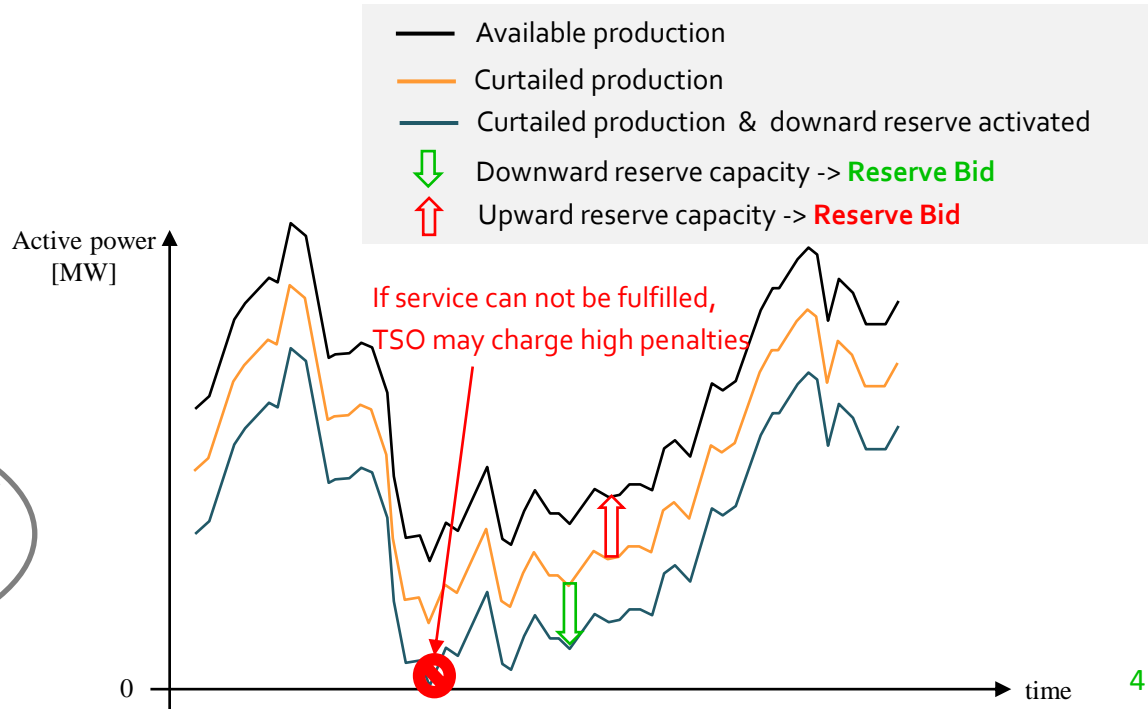
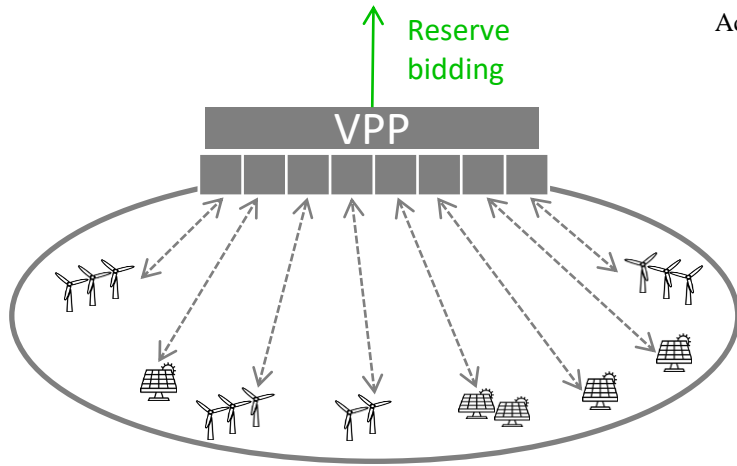
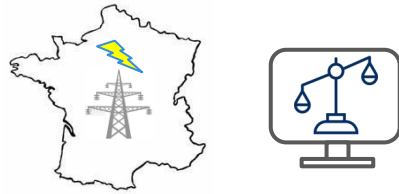
- Motivation
- Methodology: Bidding based on probabilistic forecasts
- Case Study
- Results
- Conclusion

- Variable renewables need to participate to grid balancing
  - Balancing relies on ancillary services offered by power producers



**Limit:** aggregation of variable renewable plants is necessary to reduce uncertainty in production levels

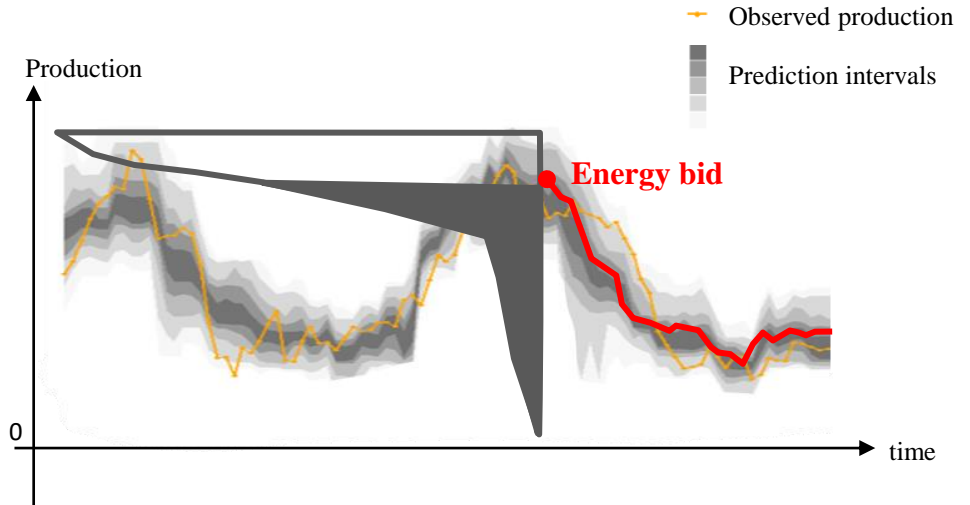
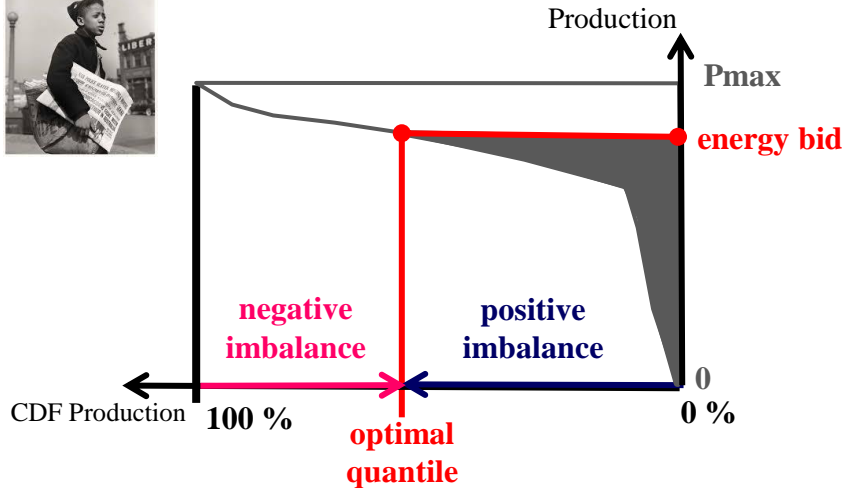
- A renewable Virtual Power Plant (VPP) offers reserve to the grid
  - Bidding in reserve markets is challenging for variable producers



# Motivation (3/3)

- Which offer strategy?

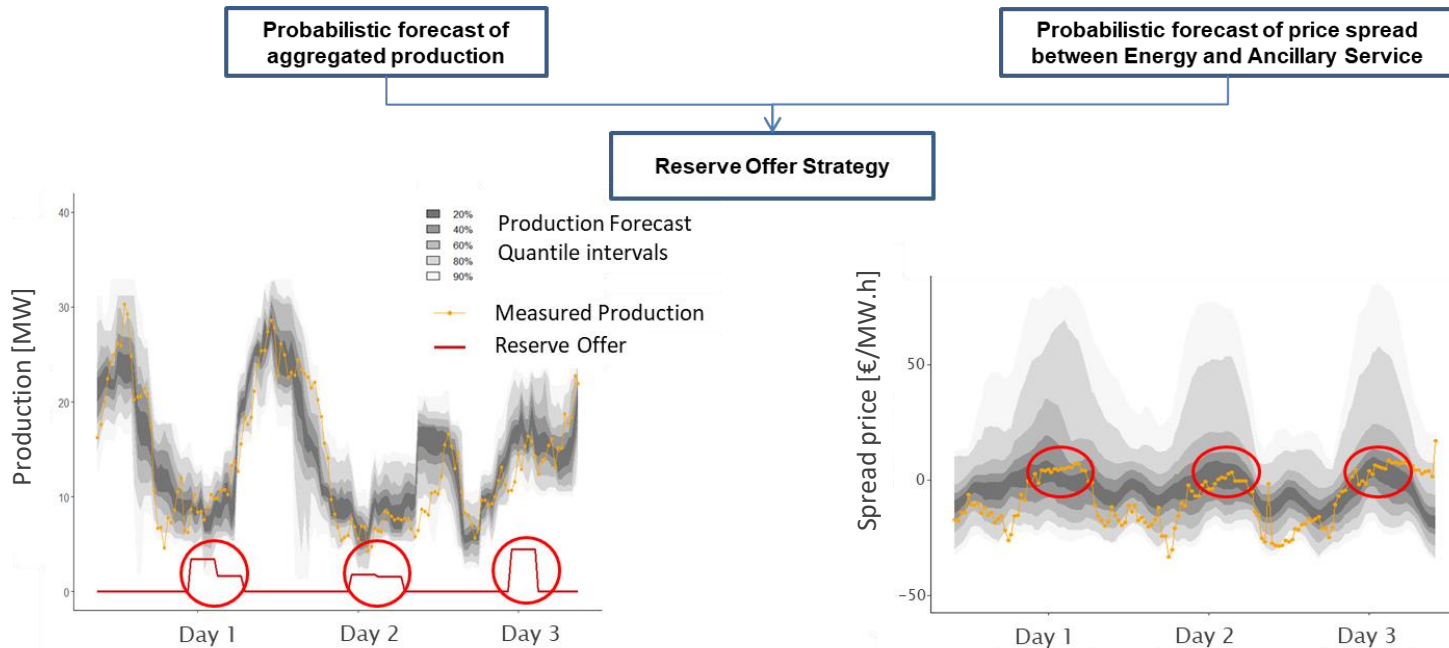
- Decision theory: need to forecast production with uncertainty quantification
- State of the art: day-ahead energy market. Prices are independent from production



**Challenge:** How can we adapt the optimal quantile strategy when bidding **reserve and energy**?

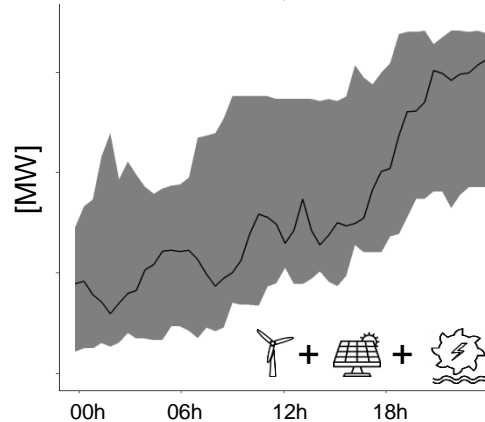
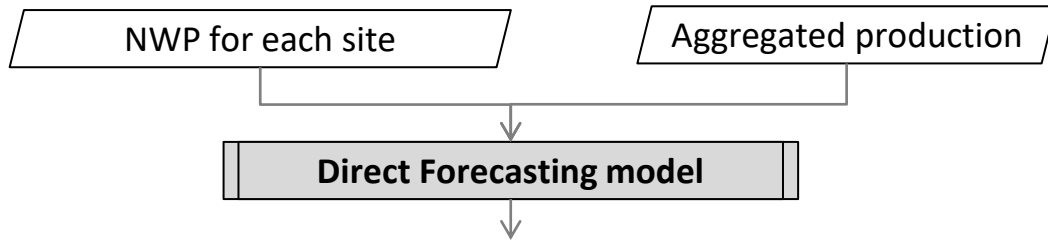
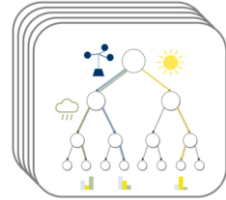
- Workflow

- Framework: **day-ahead** markets for energy and reserve, symmetrical reserve
- Reserve clearing in the morning: forecast horizons 24h-48h

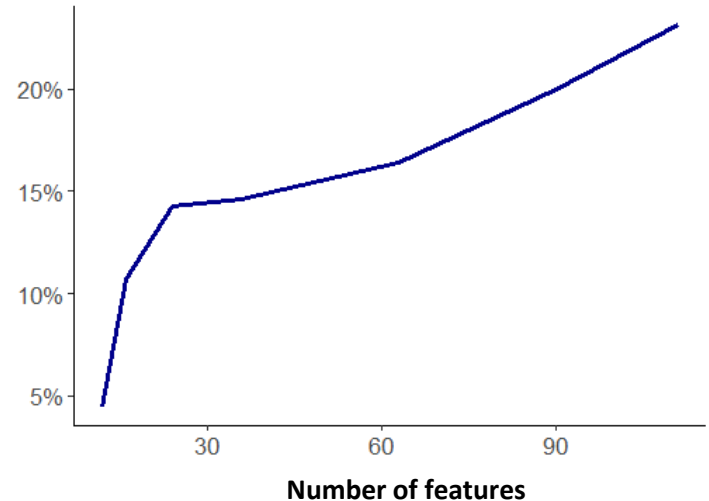


- Probabilistic forecast of aggregated production

- Direct forecast of aggregated production with Quantile Regression Forests (QRF)
- Data augmentation: NWP with several lags and lead time at each horizon



Improvement on quantile score for QRF compared to lasso linear regression



- Optimal quantile for reserve when bidding reserve and energy

- Optimal quantile on price differences (“spread”) for bids and penalties [Soares 2016]:

$$\alpha_R = \frac{\Delta \hat{\pi}_{RE}}{\Delta \hat{\pi}_{RE} + \Delta \hat{\pi}_{RE}^*}$$

- Probability of reserve activation  $\hat{a}_R$  matters:

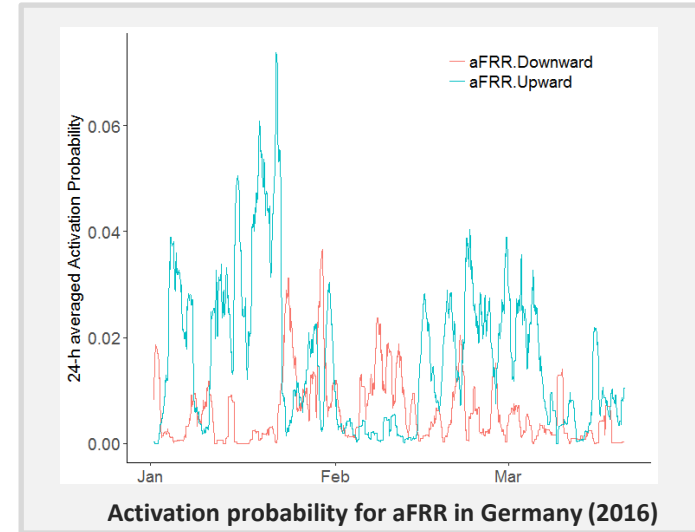
$$\Delta \hat{\pi}_{RE} = \hat{\pi}_R^\uparrow + \hat{\pi}_R^\downarrow + \hat{a}_R^\uparrow \cdot \hat{\pi}_{E_R}^\uparrow + \hat{a}_R^\downarrow \cdot \hat{\pi}_{E_R}^\downarrow - \hat{\pi}_E$$

- Difference in penalties matters also:

$$\Delta \hat{\pi}_{RE}^* = \hat{\pi}_R^* - \hat{\pi}_E^* =$$

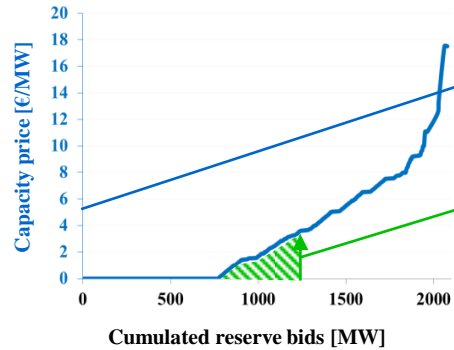
$$\underbrace{\hat{\pi}_R^\uparrow - \hat{\pi}_{R,imb}^\uparrow}_{\text{reserve imbalance price}} + \underbrace{\hat{\pi}_R^\downarrow - \hat{\pi}_{R,imb}^\downarrow}_{\text{reserve imbalance price}} - \underbrace{\hat{\pi}_E - \hat{\pi}_{E,imb}}_{\text{energy imbalance price}}$$

- Multiple price forecasts needed !





- Probabilistic forecast of price spread between reserve and energy



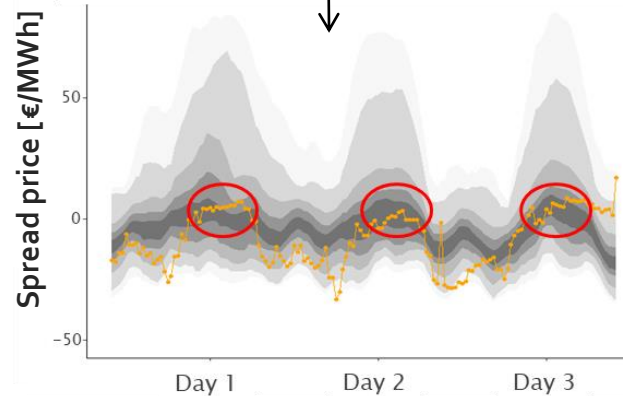
Typical reserve tender result

Deterministic reserve price forecasts (SVM)

Reserve Activation probability forecast (SVM)

Deterministic energy price forecasts (ARIMAX, MRS)

Gradient Boosting Trees



- Optimal quantile with dependence between price and production

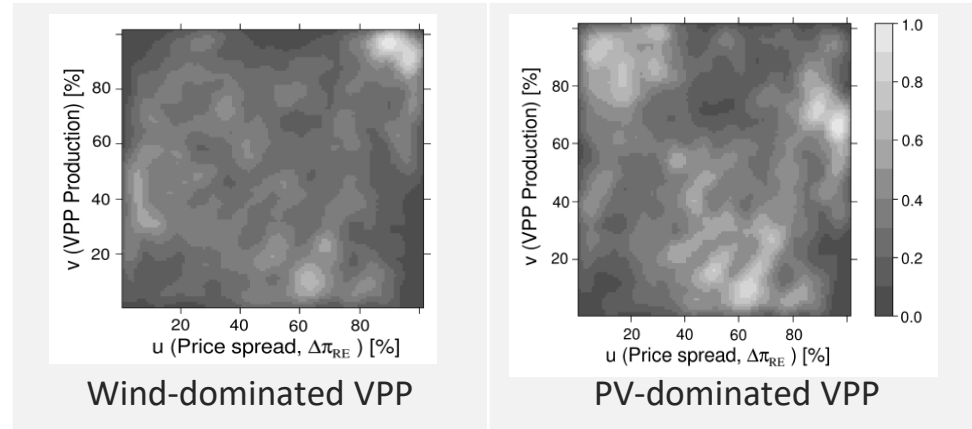
- Minimize the expected net loss (bid sales – penalties)

$$\mathbb{E}(I_R) = \int_{y=0}^R \mathbb{E}(\Delta P_{RE}^* | Y = y) \cdot (R - y) f_Y(y) dy + \int_{y=R}^1 \mathbb{E}(\Delta P_{RE} | Y = y) (y - R) f_Y(y) dy$$

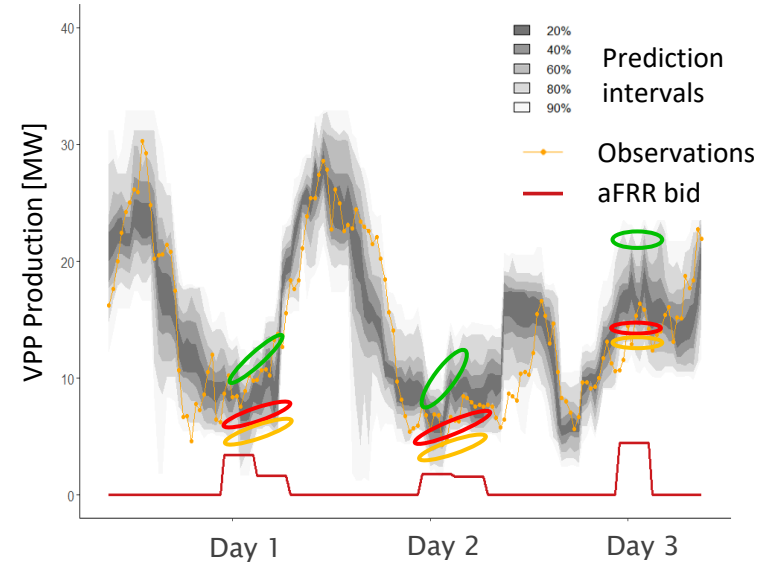
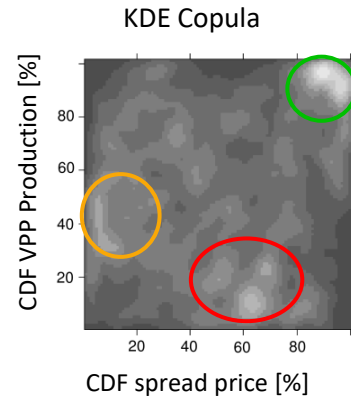
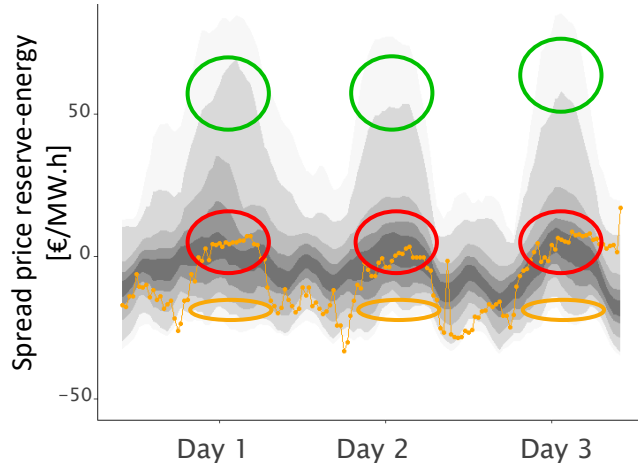
- Dependence model of spread price and VPP production by copula (KDE)

$$\mathbb{E}(\Delta P_{RE} | Y = \hat{y}) = \int_{\pi=-\infty}^{\pi=+\infty} \pi \hat{f}_{\Delta P_{RE} | Y = \hat{y}}(\pi) d\pi$$

- Energy bid = VPP mean forecast



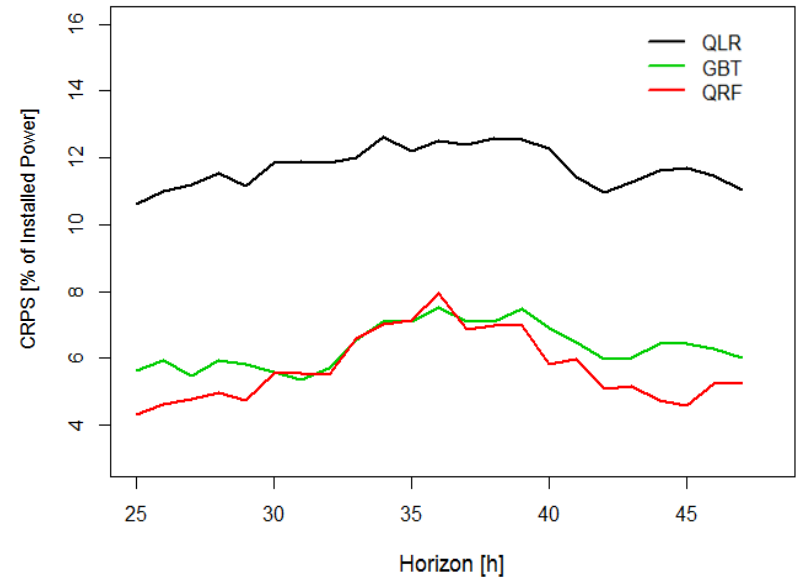
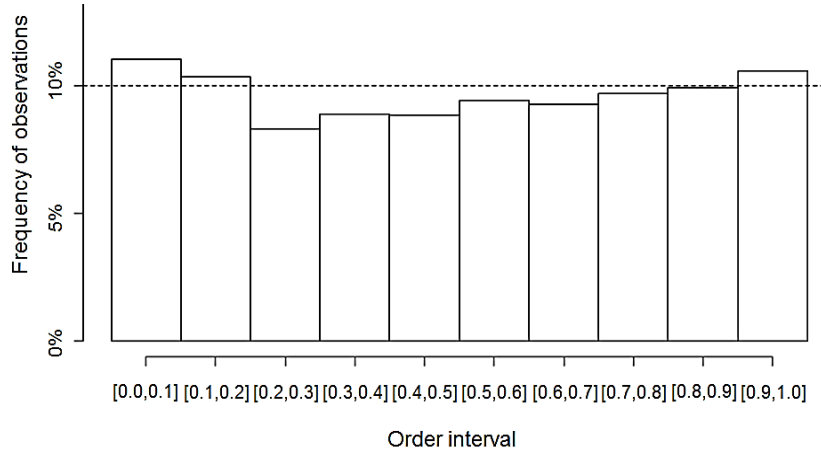
## Model overview



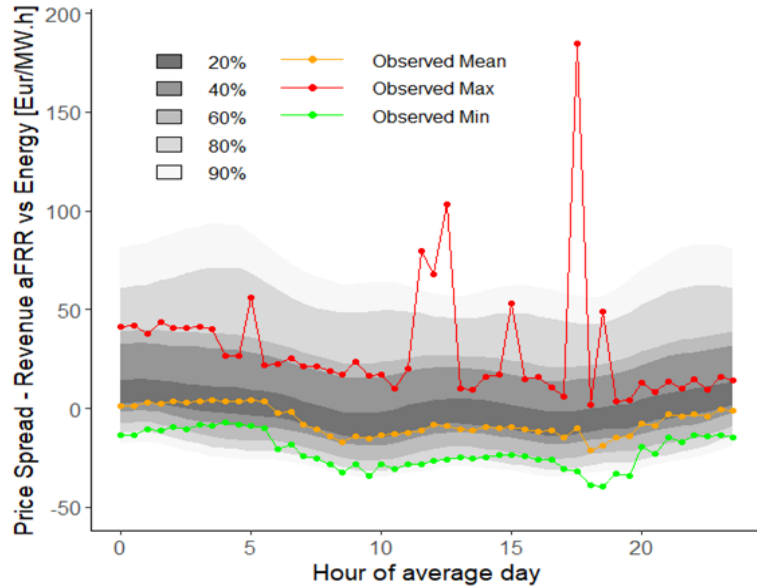
## Case study setup

- Wind – PV VPP selling energy and aFRR (German data)
- 42 MWp, 3 wind farms + 10 PV farms
- All models are trained on 09/2015 - 12/2015, and tested on 01/2016 - 03/2016
- 40 Bootstraps of VPP production per timestep

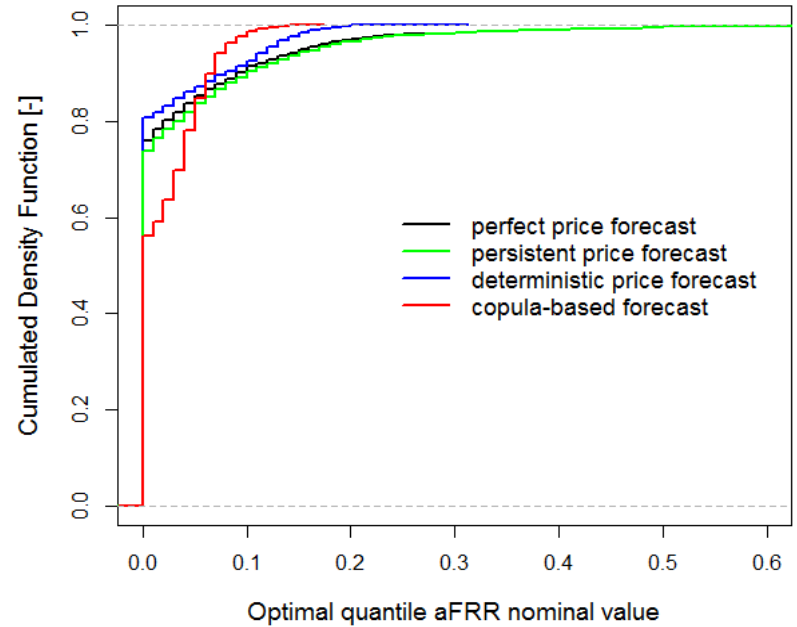
- Production forecast
  - Adequate reliability
  - QRF deals efficiently with multiple energy sources (GBT benchmark less versatile)



- Spread price forecast and optimal quantiles

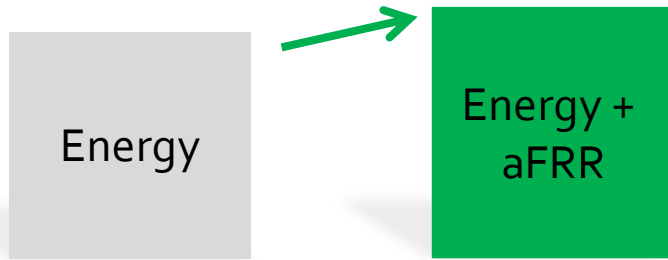


Quantile score -45% vs climatology

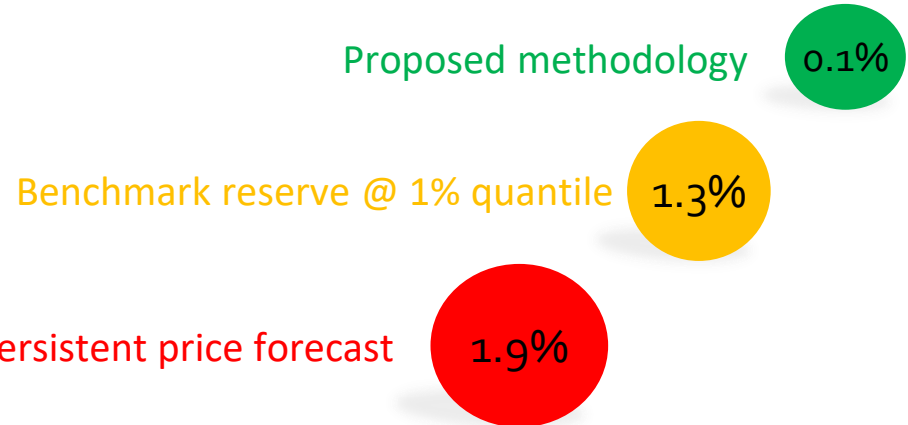


Offer based on copula is more conservative than deterministic approaches

Average revenue increases of: **+5 % to +10%**



Frequency of reserve underfulfillments:



- A bidding strategy based entirely of probabilistic forecast
  - Dependence between renewable production and prices hedges against underfulfilments
  - Increased revenue of 5% and risk of not providing reserve limited to 0.1%
- A direct regression model for aggregated production forecast
  - QRF is adapted to forecast multi-source renewable production
- Applicable to different balancing services

- Connect with us

-  : @PERSEE\_Mines

- Publications:



[Camal 18]: Camal S, Michiorri A, Kariniotakis G. Optimal Offer of Automatic Frequency Restoration Reserve from a Combined PV/Wind Virtual Power Plant. IEEE Trans Power Syst 2018;99. doi:10.1109/TPWRS.2018.2847239.

[Soares 16]: Soares T, Pinson P, Jensen T V., Morais H. Optimal Offering Strategies for Wind Power in Energy and Primary Reserve Markets. IEEE Trans Sustain Energy 2016;7:1036–45. doi:10.1109/TSTE.2016.2516767.