

# Recent advances in electricity price forecasting: A MMXXII (i.e., 2022) perspective

Rafał Weron\*

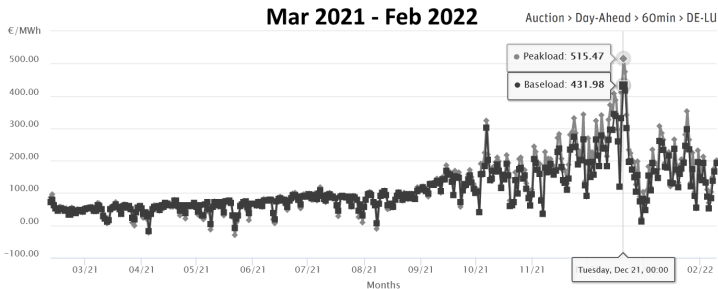
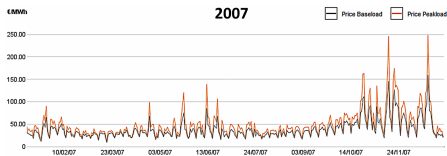
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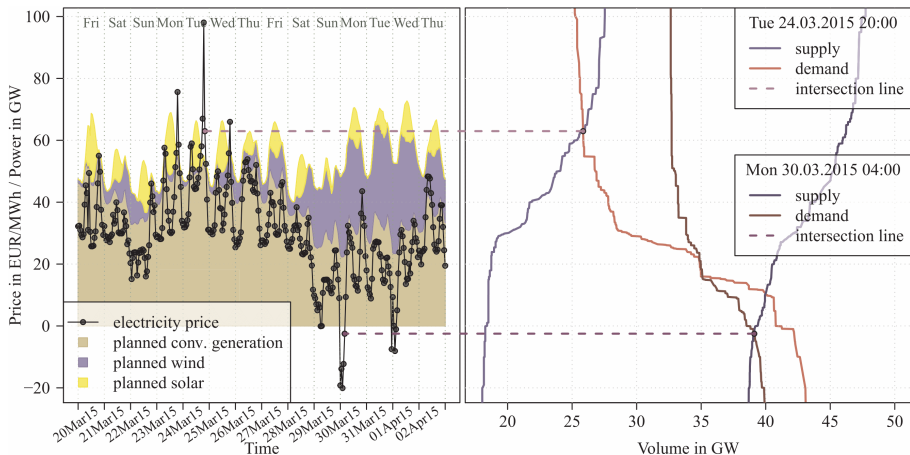
\*Based on joint work with K.Hubicka, A.Jędrzejewski, K.Maciejowska, G.Marcjasz, J.Nasiadka, W.Nitka, T.Serafin, B.Uniejewski (PWr), J.Lago (Amazon), J.Nowotarski (BNY Mellon), C.Kath, M.Narajewski, F.Ziel (Essen), C.Challu, K.Olivares (Carnegie Mellon)

# The power markets are changing ...

Here: 2007 vs. 2017 vs. 2021/22 average daily EPEX prices for Germany



# ... in particular due to increased wind ...

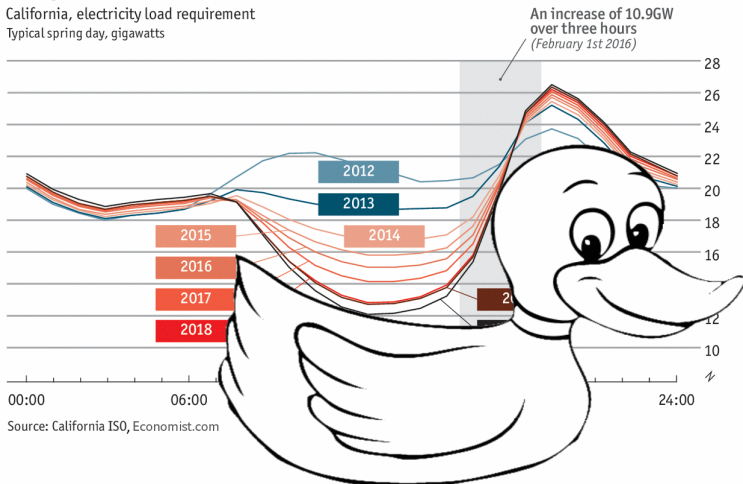


Source: Ziel & Steinert (2018, RSER)

# ... and solar penetration

## Who gets the bill?

California, electricity load requirement  
Typical spring day, gigawatts

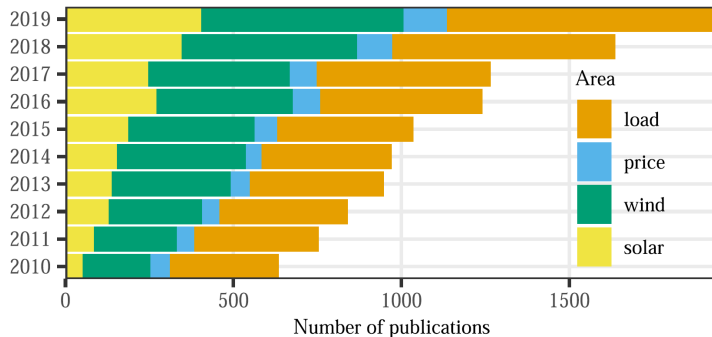


# But the (Academic) Empire ...



# Load, price, wind & solar forecasting\*

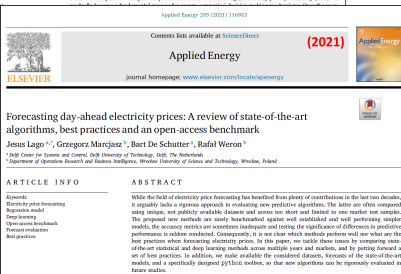
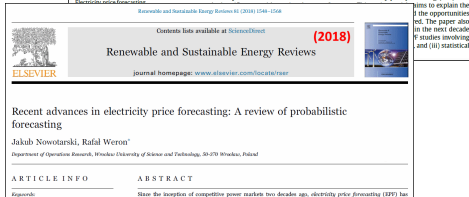
(Hong, Pinson, Wang, Weron, Yang & Zareipour, 2020, IEEE OAJPE)



\* Scopus indexed

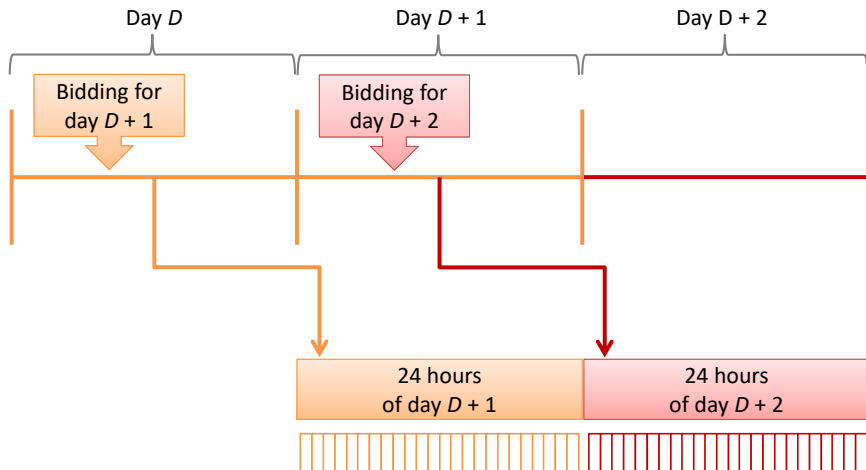
# Agenda

- 1 Intro
- 2 Model evolution
  - Models and frameworks
  - Regularization
  - Going deep
- 3 Calibration windows
  - Averaging
  - Identifying breakpoints
- 4 Beyond point forecasts
  - Probabilistic
  - Path (ensemble)
- 5 Financial evaluation
  - Euros not errors



# The workhorse of European power trading

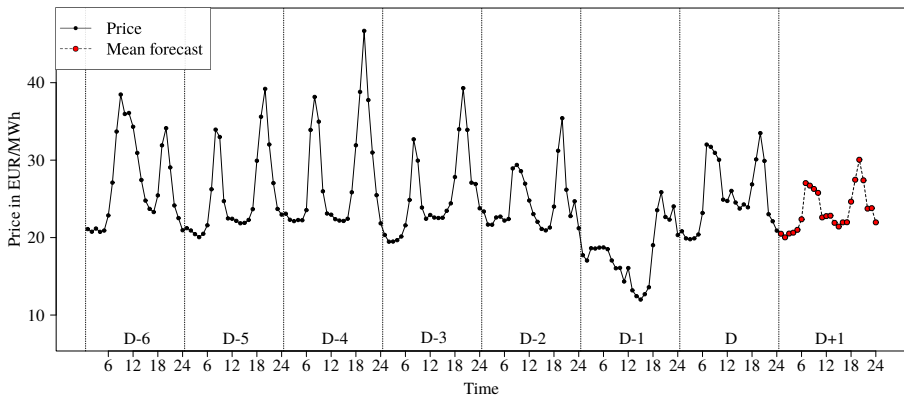
The day-ahead market (> 90% of papers)



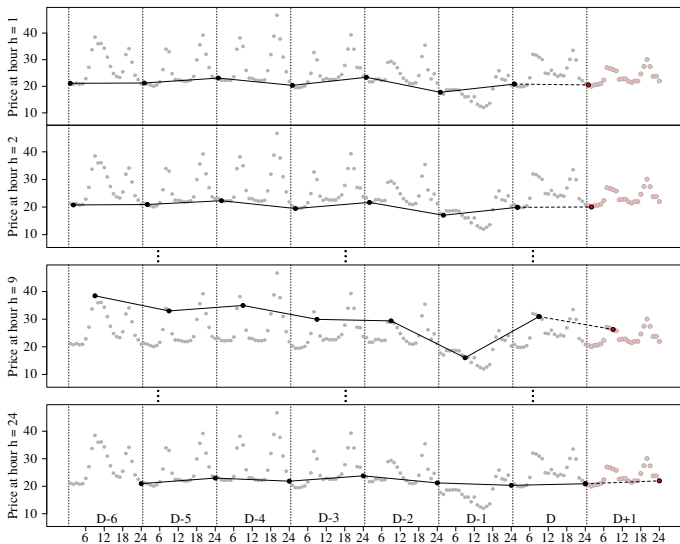


# Day-ahead point forecasting: Univariate ...

(Ziel & Weron, 2018, ENEECO)



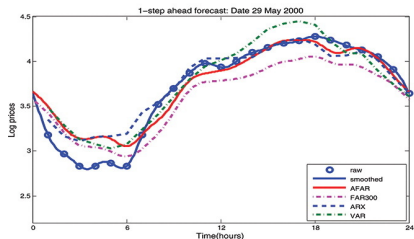
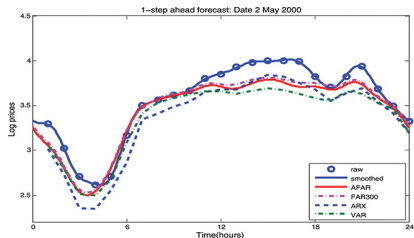
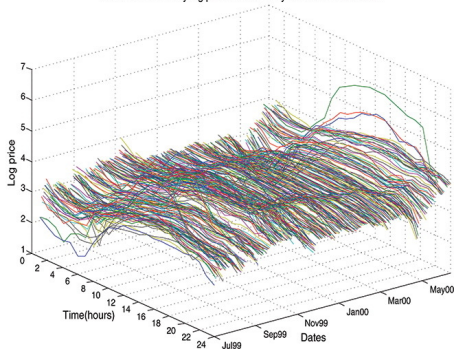
## ... multivariate ...



# ... or functional (data analysis)?

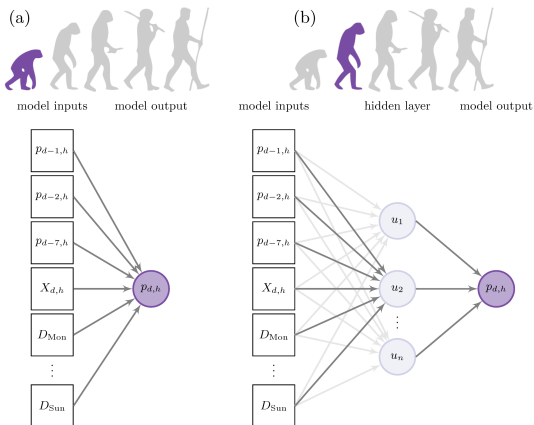
(Chen & Li, 2017, JBES; Chen et al., 2019, Ann.Appl.Stat.)

Smoothed electricity log price curves 5 July 1999—11 June 2000



# Which modeling framework?

(Jędrzejewski, Lago, Marcjasz & Weron, 2022, IEEE-PEM)



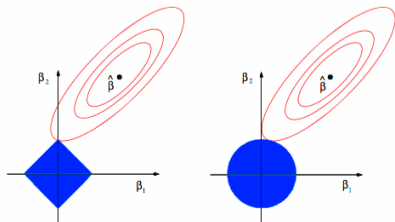
Early EPF models: **(a)** linear regression and **(b)** a single-output shallow neural network

# LASSO-Estimated AR (LEAR)

(Uniejewski et al., 2016; Ziel, 2016; Ziel & Weron, 2018; Jędrzejewski et al., 2022)

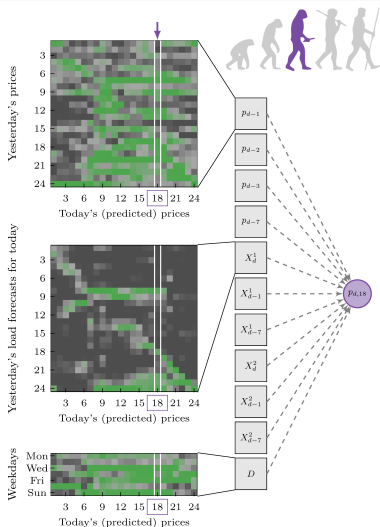
Minimize the residual sum of squares (RSS) + a penalty:

$$\hat{\beta} = \underset{\beta_j}{\operatorname{argmin}} \left\{ \text{RSS} + \lambda \sum_{j=1}^n |\beta_j|^q \right\}$$



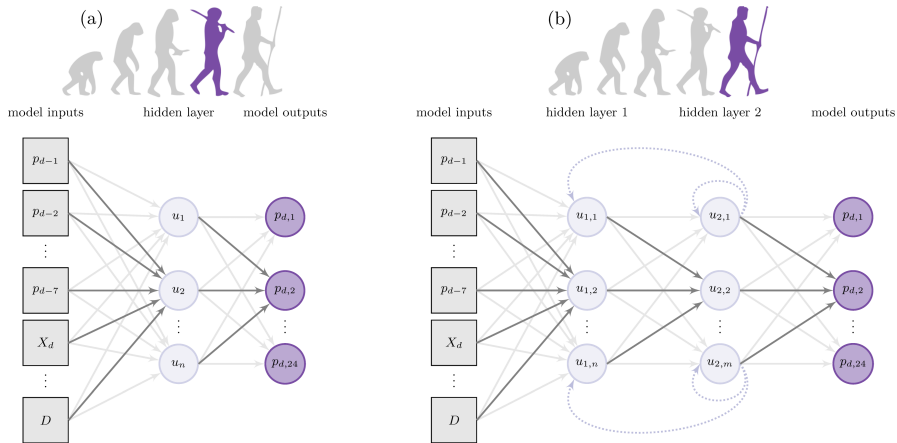
Blue areas – constraint regions, e.g.,  $|\beta_1| + |\beta_2| \leq t$

Red ellipses – contours of the LS error function



# Multi-output and deep neural networks (DNNs)

(Lago et al., 2021, APEN; Jędrzejewski et al., 2022, IEEE-PEM)



Multi-output NN architectures: (a) shallow and (b) deep with 2 hidden layers

# What about performance?

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(2021)



ELSEVIER



## Forecasting day-ahead electricity prices: A review of state-of-the-art algorithms, best practices and an open-access benchmark

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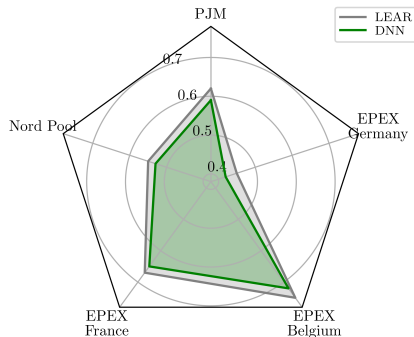
### ARTICLE INFO

**Keywords:**  
Electricity price forecasting  
Regression model  
Deep learning  
Open-access benchmark  
Forecast evaluation  
Best practices

### ABSTRACT

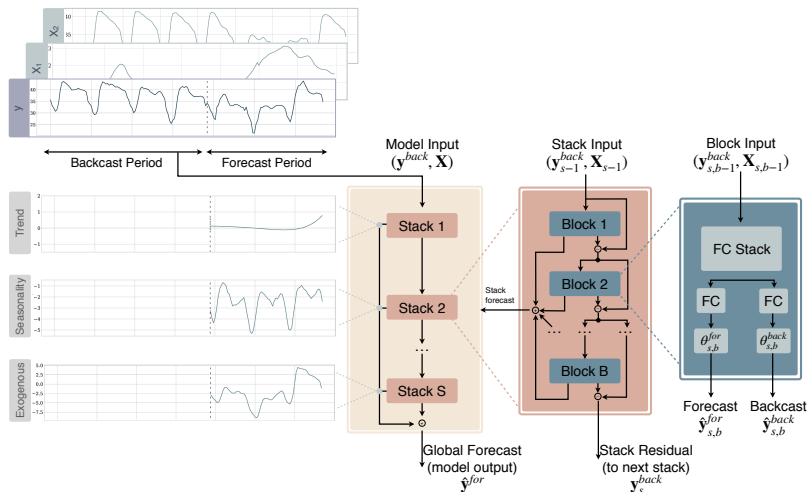
While the field of electricity price forecasting has benefited from it arguably lacks a rigorous approach to evaluating new prediction using unique, not publicly available datasets and across too short. The proposed new methods are rarely benchmarked against well models, the accuracy metrics are sometimes inadequate and testing performance is seldom conducted. Consequently, it is not clear what best practices when forecasting electricity prices. In this paper, of-the-art statistical and deep learning methods across multiple sets of best practices. In addition, we make available the considered models, and a specifically designed python toolbox, so that new future studies.

rMAE (relative to a naive forecast)



# Interpretable NNs: NBEATSx

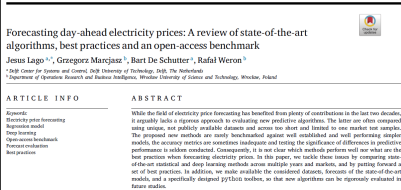
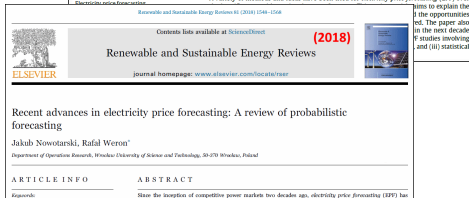
(Olivares, Challu, Marcjasz, Weron & Dubrawski, 2022, IJF)





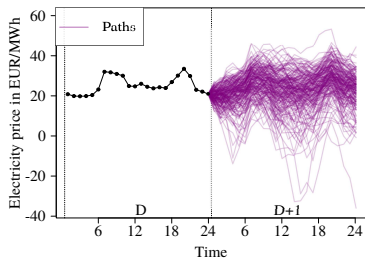
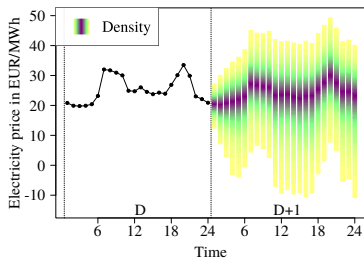
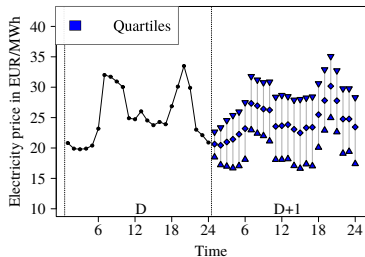
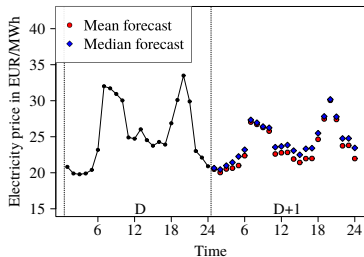
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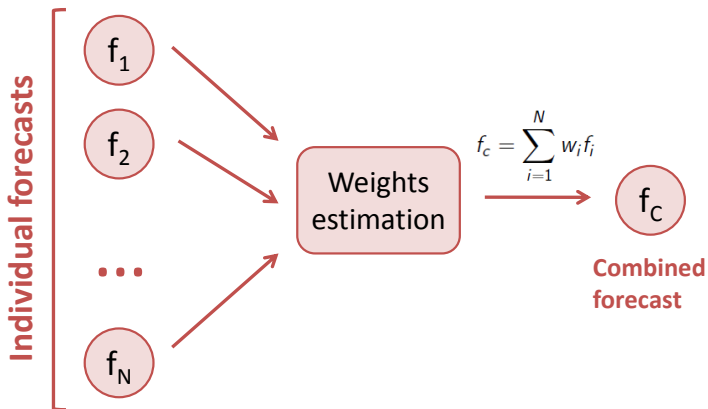


# Point $\rightarrow$ probabilistic $\rightarrow$ path forecasting

(< 10% of EPF papers)



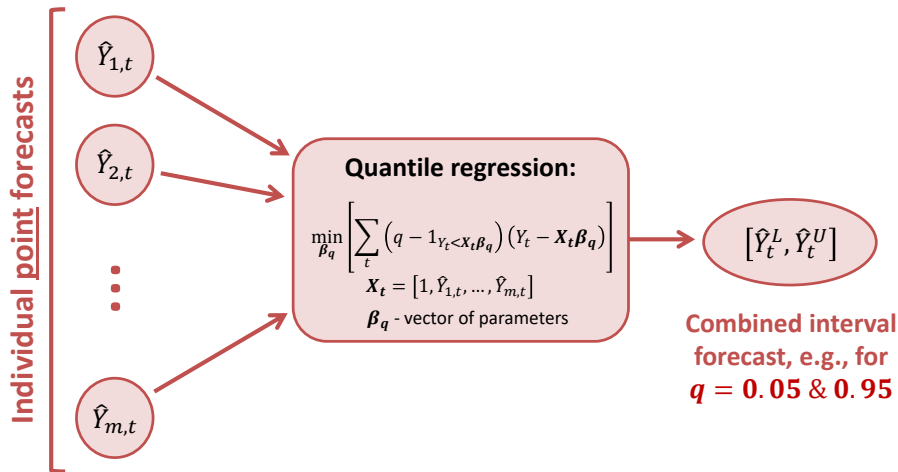
# Point forecast averaging: The idea



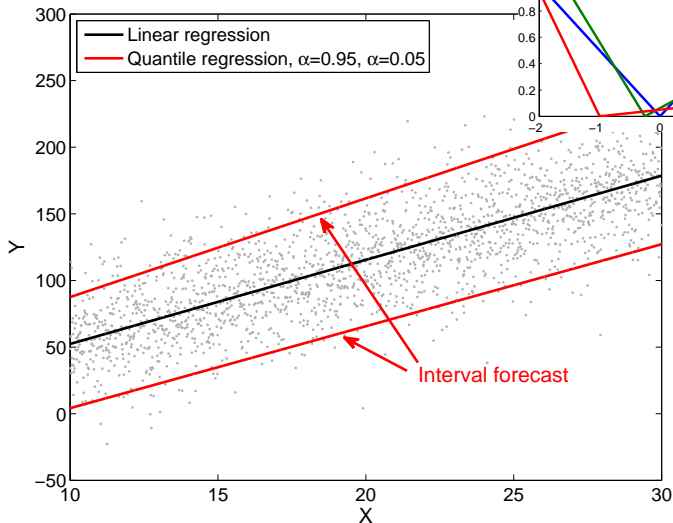
- Dates back to the 1960s and the works of Bates, Crane, Crotty & Granger

# Quantile Regression Averaging: The idea

(Nowotarski & Weron, 2015, COST)



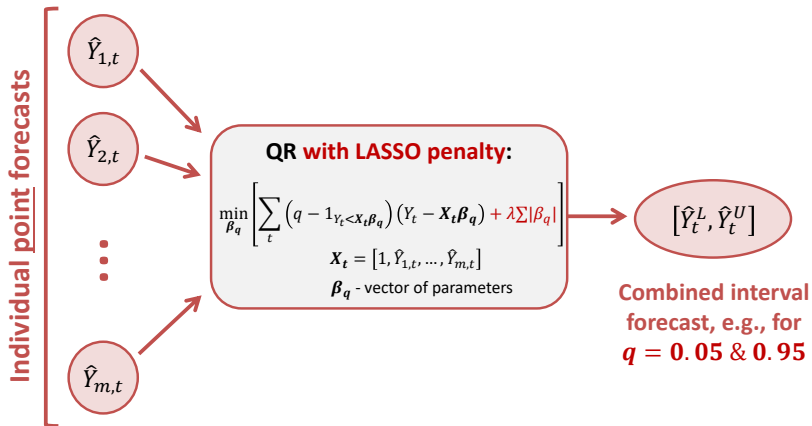
# Quantile regression



# LQRA: When the number of predictors is large

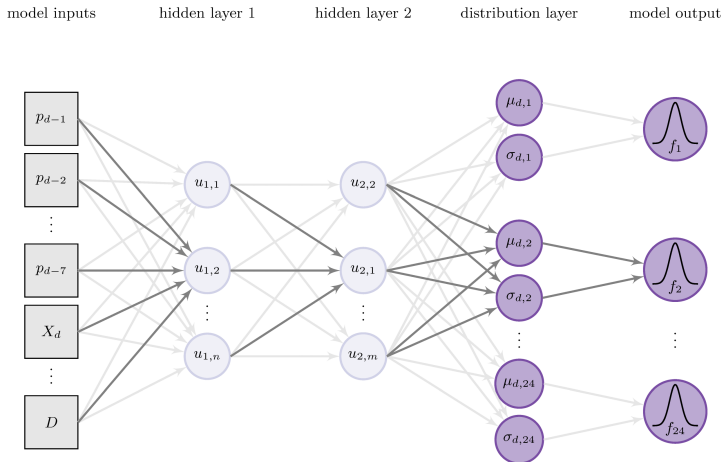
(Uniejewski & Weron, 2021, ENEECO)

~ 5% improvement over QRA



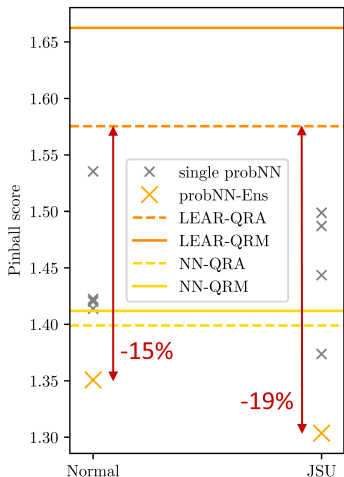
# Probabilistic neural nets

(Jędrzejewski et al., 2022, IEEE-PEM; Marcjasz, Narajewski, Weron & Ziel, 2022, WP)

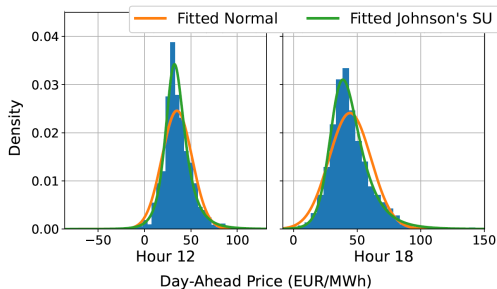


# Perform surprisingly well ... after averaging

(Marcjasz, Narajewski, Weron & Ziel, 2022, WP)



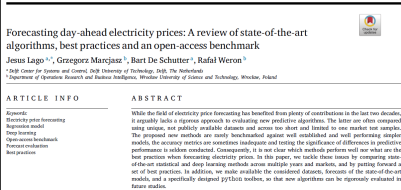
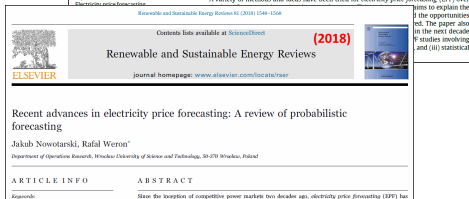
	MAE	RMSE	pinball
Naive	9.336	14.378	3.585
LEAR-QRA	4.161	6.699	1.575
LEAR-QRM	4.285	6.782	1.662
NN-QRA	3.668	5.830	1.399
NN-QRM	3.670	5.822	1.412
probNN-Ens N	3.663	5.969	1.351
probNN-Ens JSU	3.542	5.741	1.304





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# Rafał Weron


Professor of Management Science (Energy Forecasting)

Home Publications Projects S3 Seminar Conferences Students

## Monographs, reviews and edited volumes

 J. Lago, G. Marcjasz, B. De Schutter, **R. Weron** (2021) *Forecasting day-ahead electricity prices: A review of state-of-the-art algorithms, best practices and an open-access benchmark*, Applied Energy 293, 116983  
**Open Access** (doi: [10.1016/j.apenergy.2021.116983](https://doi.org/10.1016/j.apenergy.2021.116983))

- The **epftoolbox** including Python codes for the two benchmark models (LEAR, DNN) and datasets is available from [GitHub](#)

 T. Hong, P. Pinson, Y. Wang, **R. Weron**, D. Yang, H. Zareipour (2020) *Energy forecasting: A review and outlook*, IEEE Open Access Journal of Power and Energy 7, 376-388 **Open Access** (Invited Paper; doi: [10.1109/OAJPE.2020.3029979](https://doi.org/10.1109/OAJPE.2020.3029979))

- IEEE Open Access Journal of Power and Energy was formerly known as *IEEE Power and Energy Technology Systems Journal*