Forecasting of heat demand in district heating systems and their integration into smart grid controllers – Fractals, ensembles and expert advisers

COPENHAGEN, 13 SEPTEMBER 2017

Davy Geysen – Gowri Suryanarayana

Overview

Part I	The context: STORM
Part II	Machine learning
Part III	Expert Advice
Part IV	Results
Part V	Conclusions

Self-organising Thermal Operational Resource Management

- **4th generation DHC**
- **Generic intelligent DHC network controller**
  - Thermal load forecasting
- **Karlshamn DHS**
  - **100 buildings**

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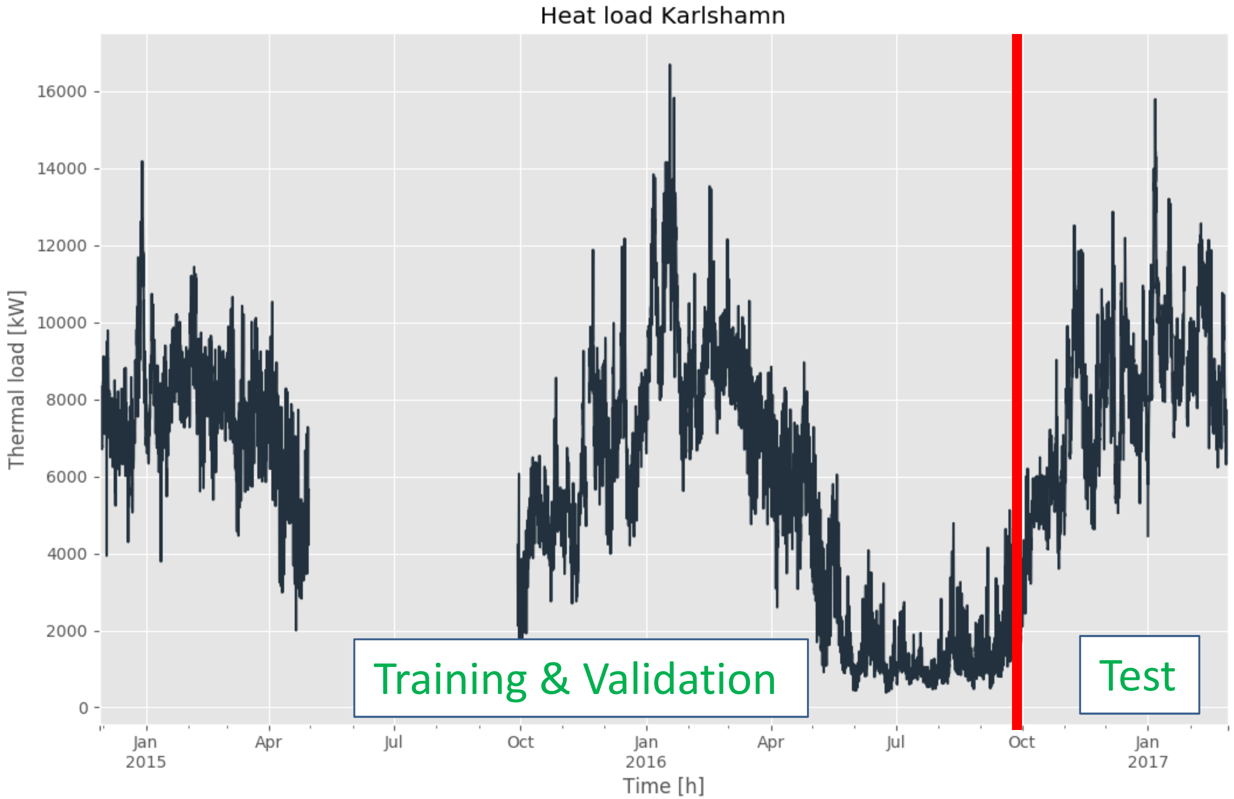
Machine learning

- **Building a model from sample inputs**



Supervised Machine learning

4DH
4th Generation District Heating Technologies and Systems

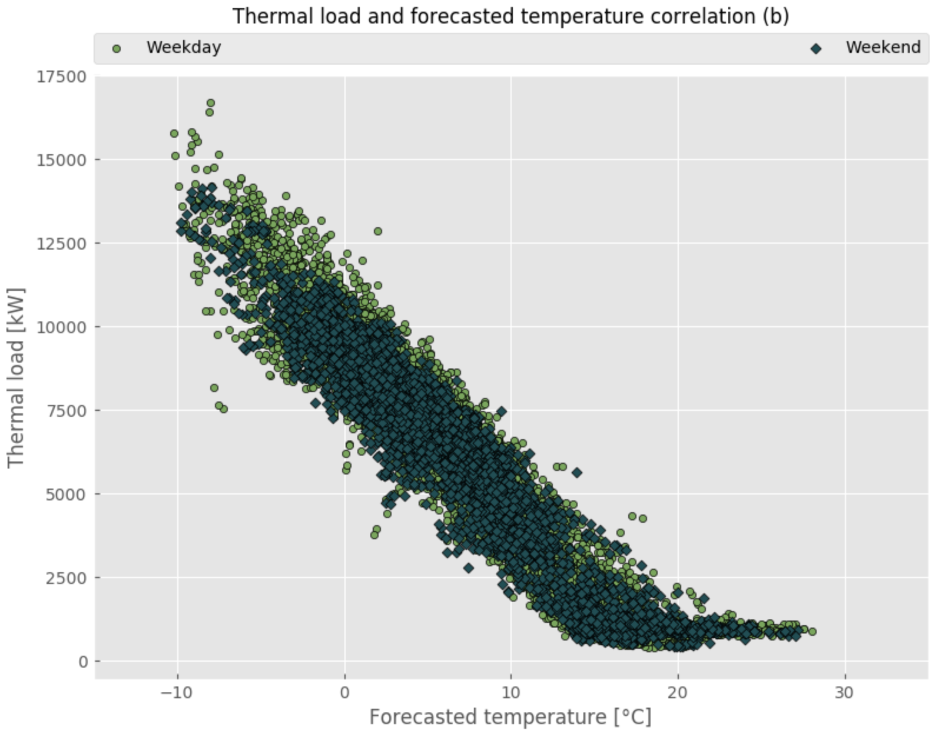
reINVEST

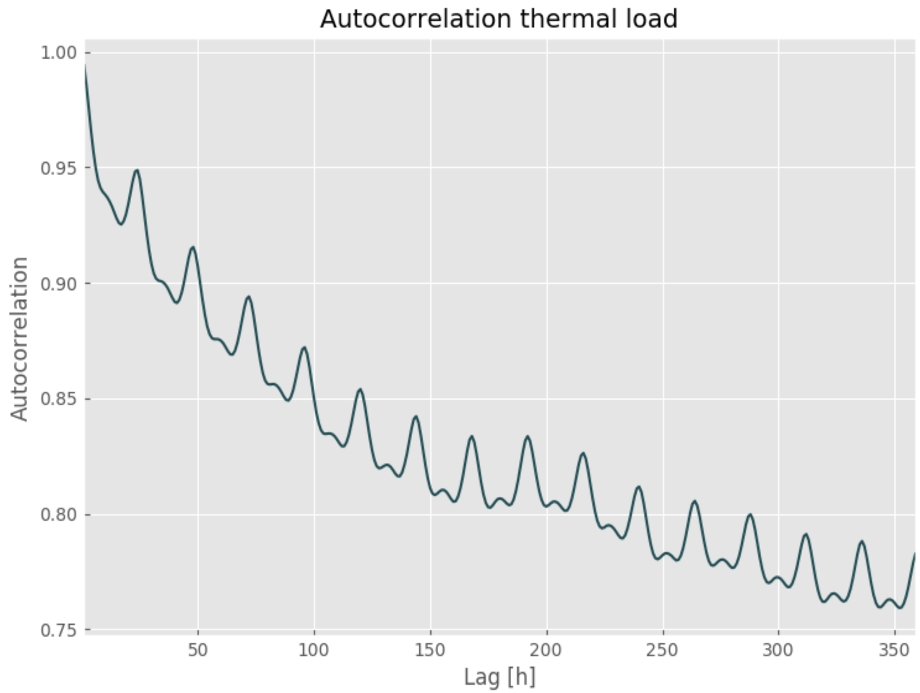
- **Input vector (features) to output value (target)**
  - **Multiple linear regression (LR)**
  - **Decision Tree Learning[1]**
    - **Extremely-Randomized Trees (ETR)**
  - **Artificial Neural Network (ANN)**

2: Pierre Geurts, Damien Ernst, and Louis Wehenkel. 2006. Extremely randomized trees. *Mach. Learn.* 63, 1 (April 2006), 3-42. DOI=http://dx.doi.org/10.1007/s10994-006-6226-1

Feature selection

- **Temperature forecast and historic thermal load**





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www.4dh.eu www.reinvestproject.eu www.heatroadmap.eu

4DH 4th Generation District Heating Technologies and Systems

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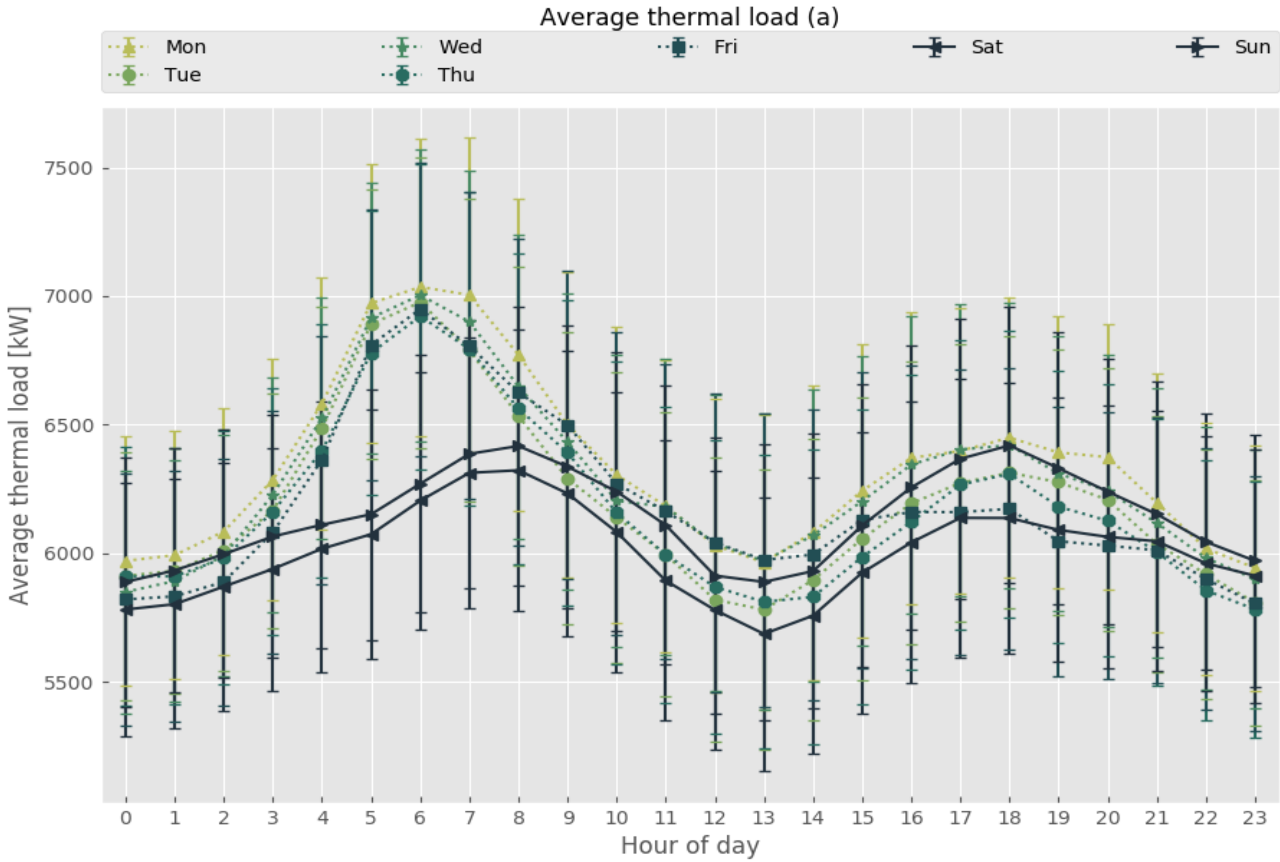
STORM DISTRICT ENERGY CONTROLLER

Feature selection

- **Timing information**



Feature selection

- **Temperature forecast + lags**
  - **Quadratic and cubic dependence on the above temp features**
- **Thermal load + lags**
  - **Quadratic and cubic dependence on the above thermal load features**
- **Timing information**
  - **Day of the year, day of the week, hour of the day**

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Expert advice

- **Combine N thermal load forecasting experts**
  - **Multiple linear regression, ExtRa Trees regressor, Artificial Neural Network**

- **Track the best expert**
  - Losses and regret
  - Minimize $R_k = \hat{L}_k - \min_{1 \leq i \leq N} L_{i,k}$

- **Fixed-share forecaster (FS)[2]**

2: P. Gaillard, Y. Goude, Forecasting electricity consumption by aggregating experts; how to design a good set of experts, in: A. Antoniadis, X. Brossat, J.-M. Poggi (Eds.), Modeling and Stochastic Learning for Forecasting in High Dimensions, Vol. 217 of Lecture Notes in Statistics, Springer, 2015, pp. 95{115. doi:10.1007/978-3-319-18732-7.

Expert advice

Algorithm 1 Prediction of thermal load with expert advice

1: Parameters: decision space $\mathbb{R}_{\geq 0}$, outcome space $\mathbb{R}_{\geq 0}$, loss function ℓ, set ε of expert indices

2: **for** $k = 1, 2, \ldots$ **do**

3: prediction of experts $\{F_{E,k} : E \in \varepsilon\}$, expert advice;

4: reveal expert advice to forecaster;

5: prediction of forecaster based on expert advice $\hat{P}_k$

6: calculate forecaster's loss $\ell\left(\hat{P}_k, Y_k\right)$ and the expert losses $\ell\left(F_{E,k}, Y_k\right)$

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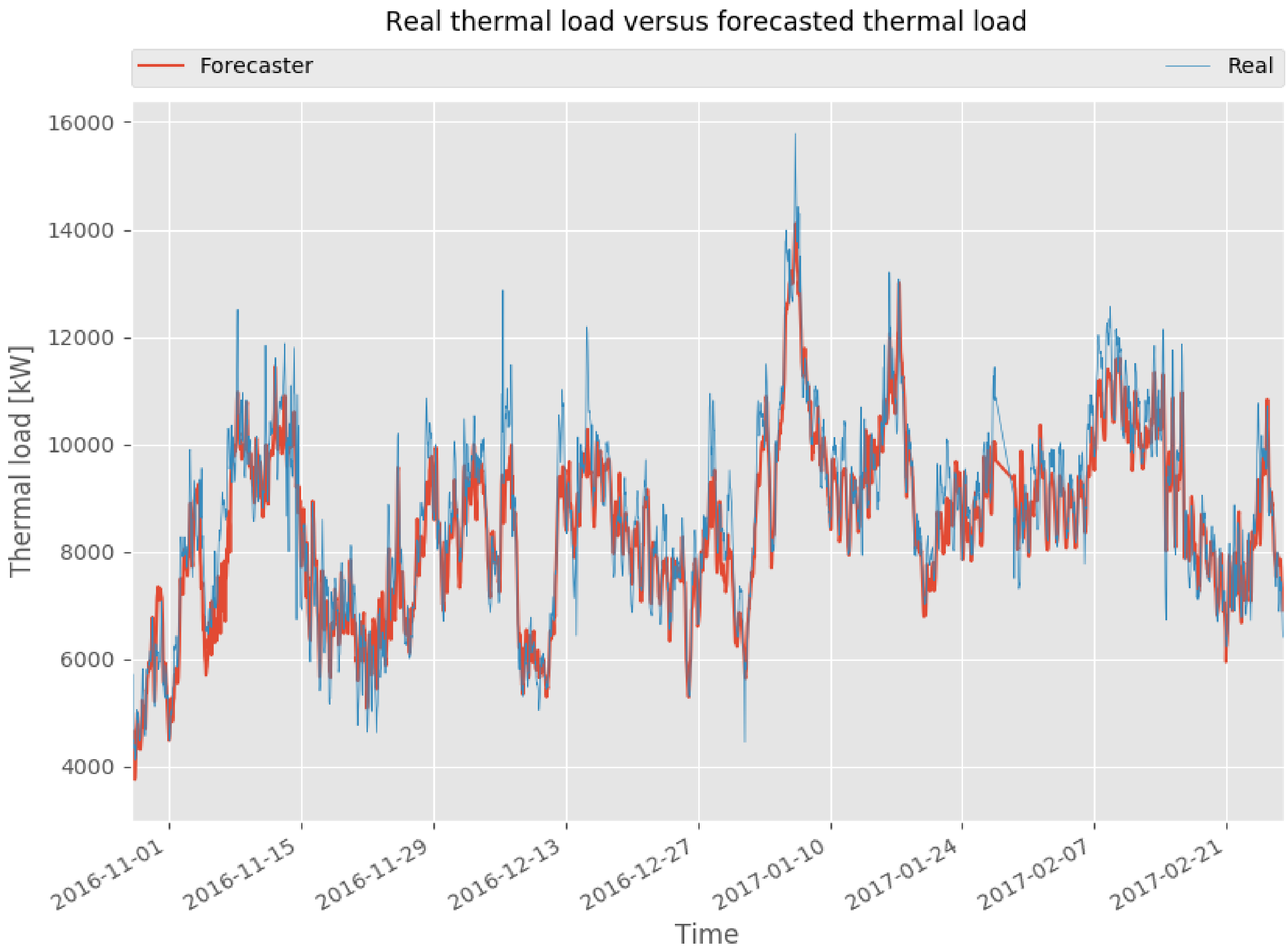
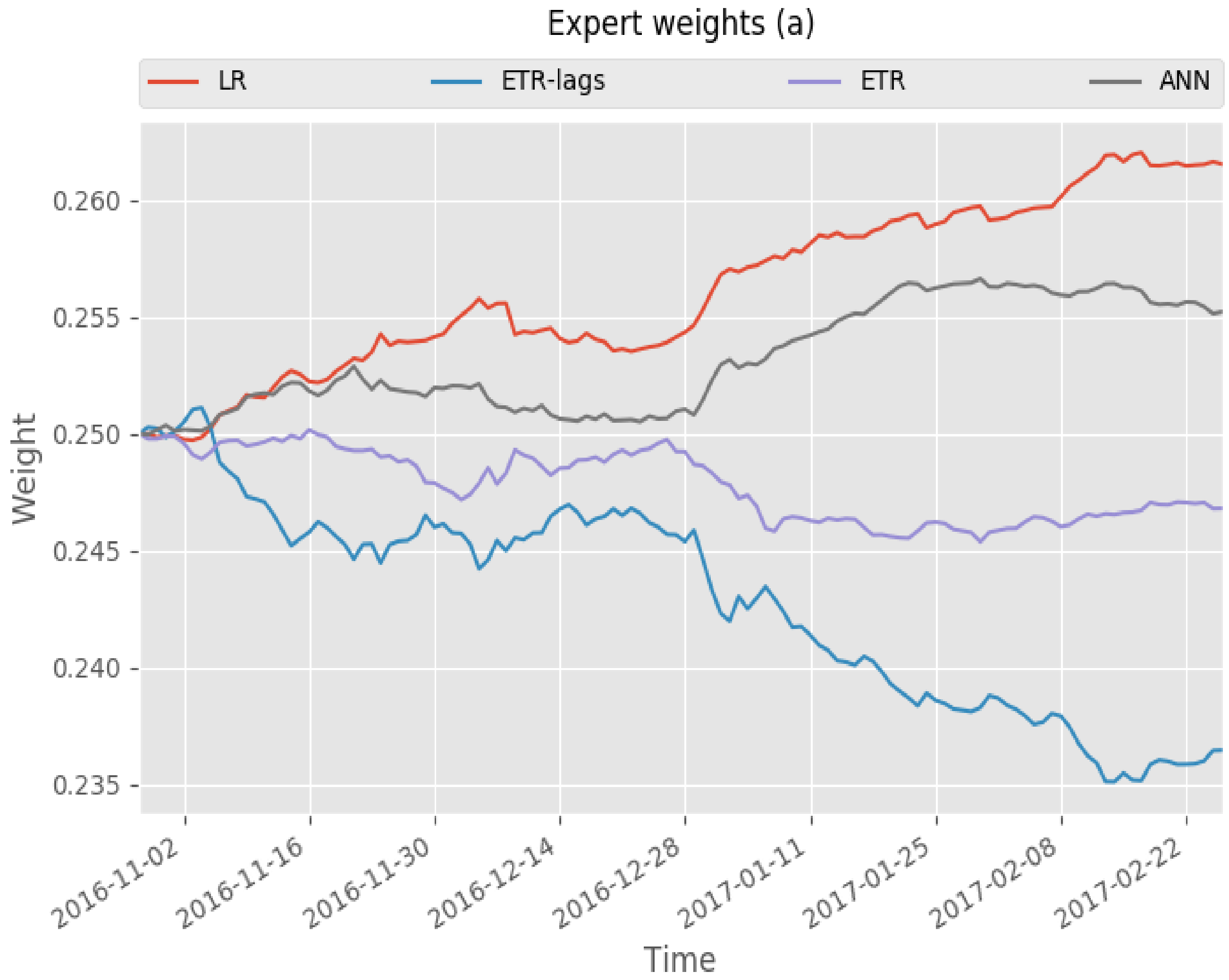
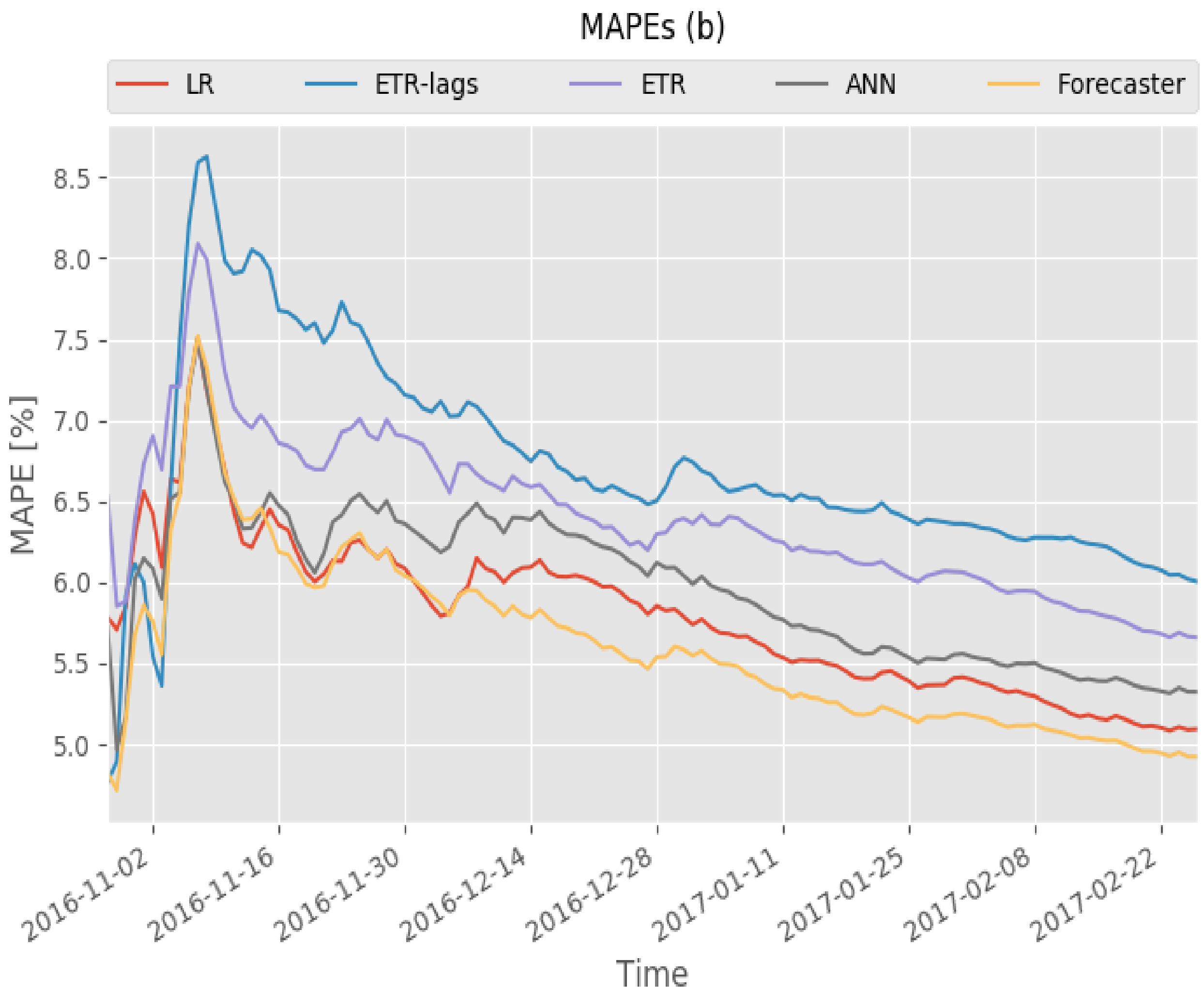
Results Expert Advice



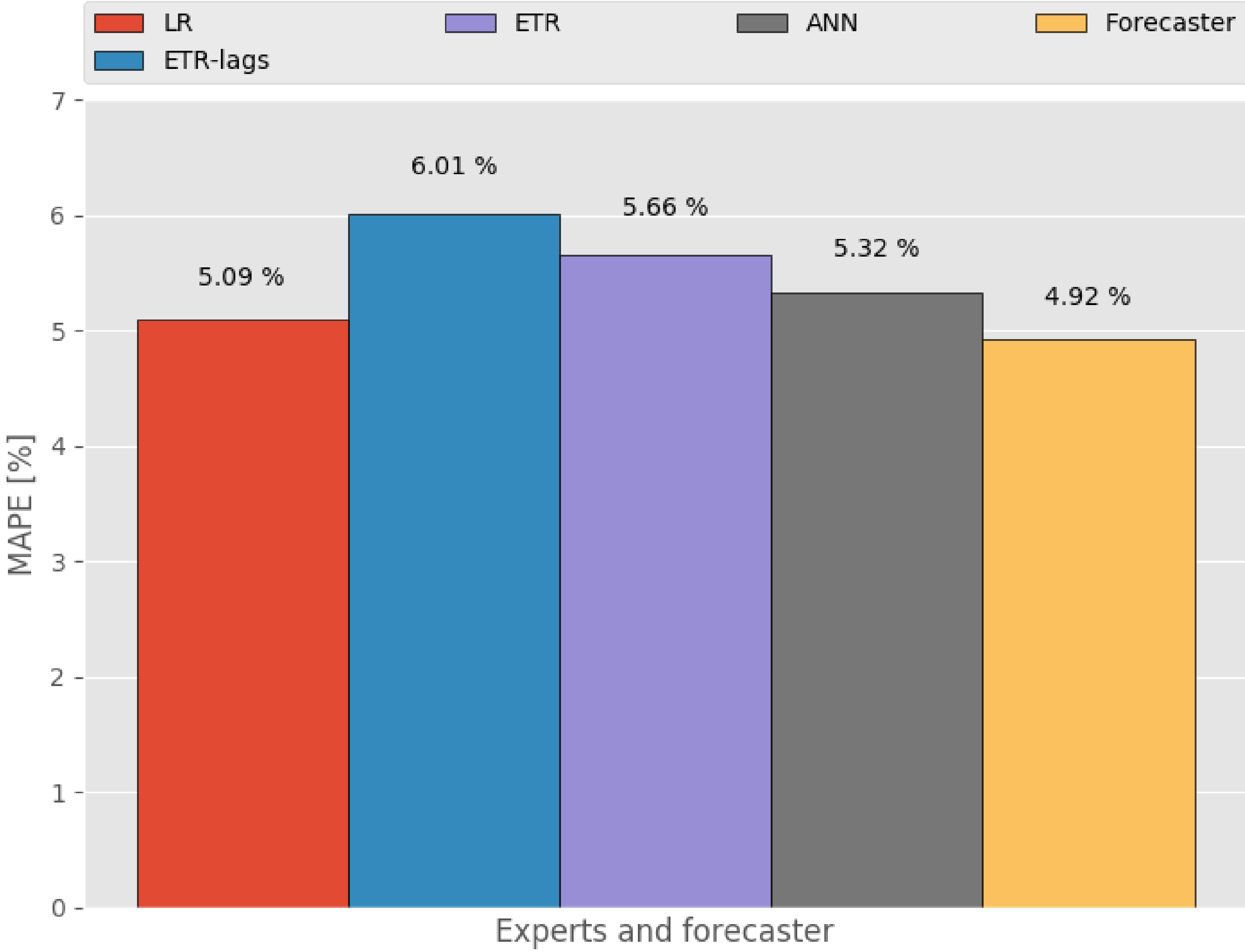
Results Expert Advice



Results Expert Advice



Results Expert Advice



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Conclusions

- **Robust and generic thermal load forecaster**
  - Easy to add and remove experts
  - Reduces susceptibility to changes in the DHS
  - Sufficient training data needed
  - Python 3.5, scikit-learn

- **Outperforms fractals**

- **Integration of forecaster in smart controller**
  - Shift peak production to integrate more renewables

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