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Bundesministerium
für Bildung
und Forschung

# ML-BASED PRICE FORECASTS IN THE OPEN ELECTRICITY MARKET MODEL AMIRIS

**Felix Nitsch[1,*], Christoph Schimeczek[1]**

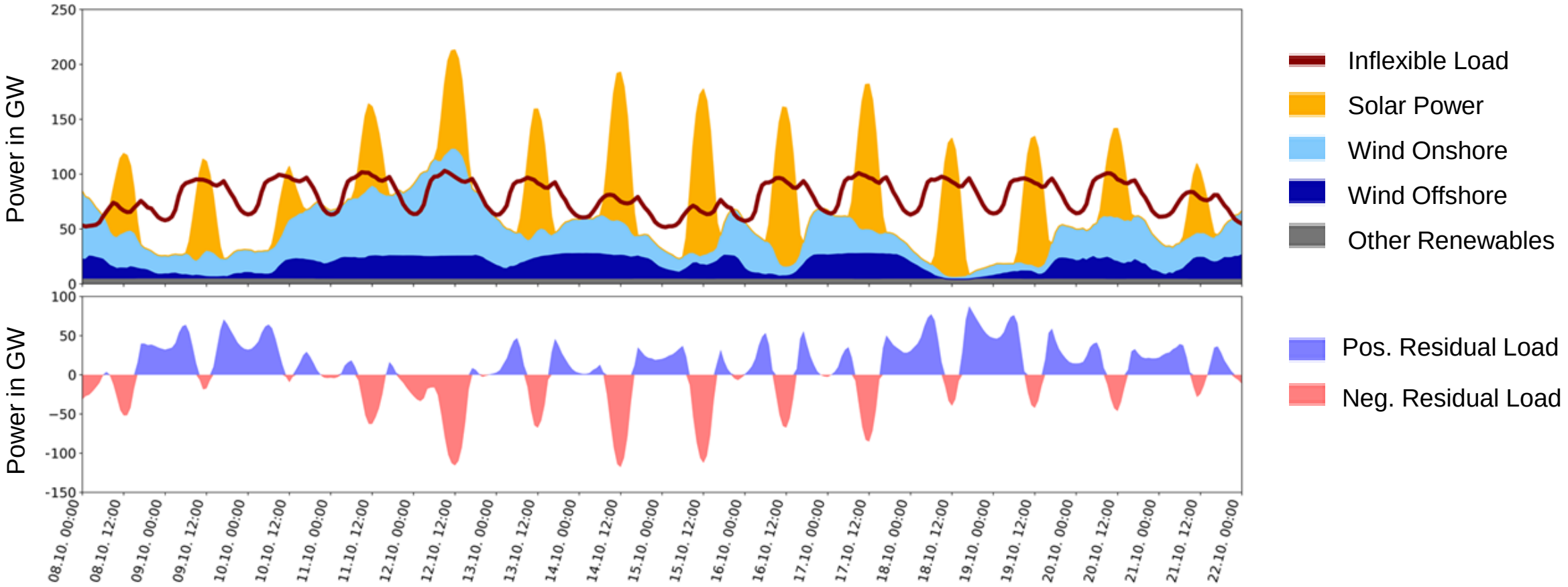
February, 2025

**Acknowledgements:** Valentin Bertsch, Kristina Nienhaus on behalf of the Energy Economics Group

[1] German Aerospace Center | Institute of Networked Energy Systems | Energy Systems Analysis
* felix.nitsch@dlr.de

DLR

# Introduction
## Challenges of Intermittent Energy Sources



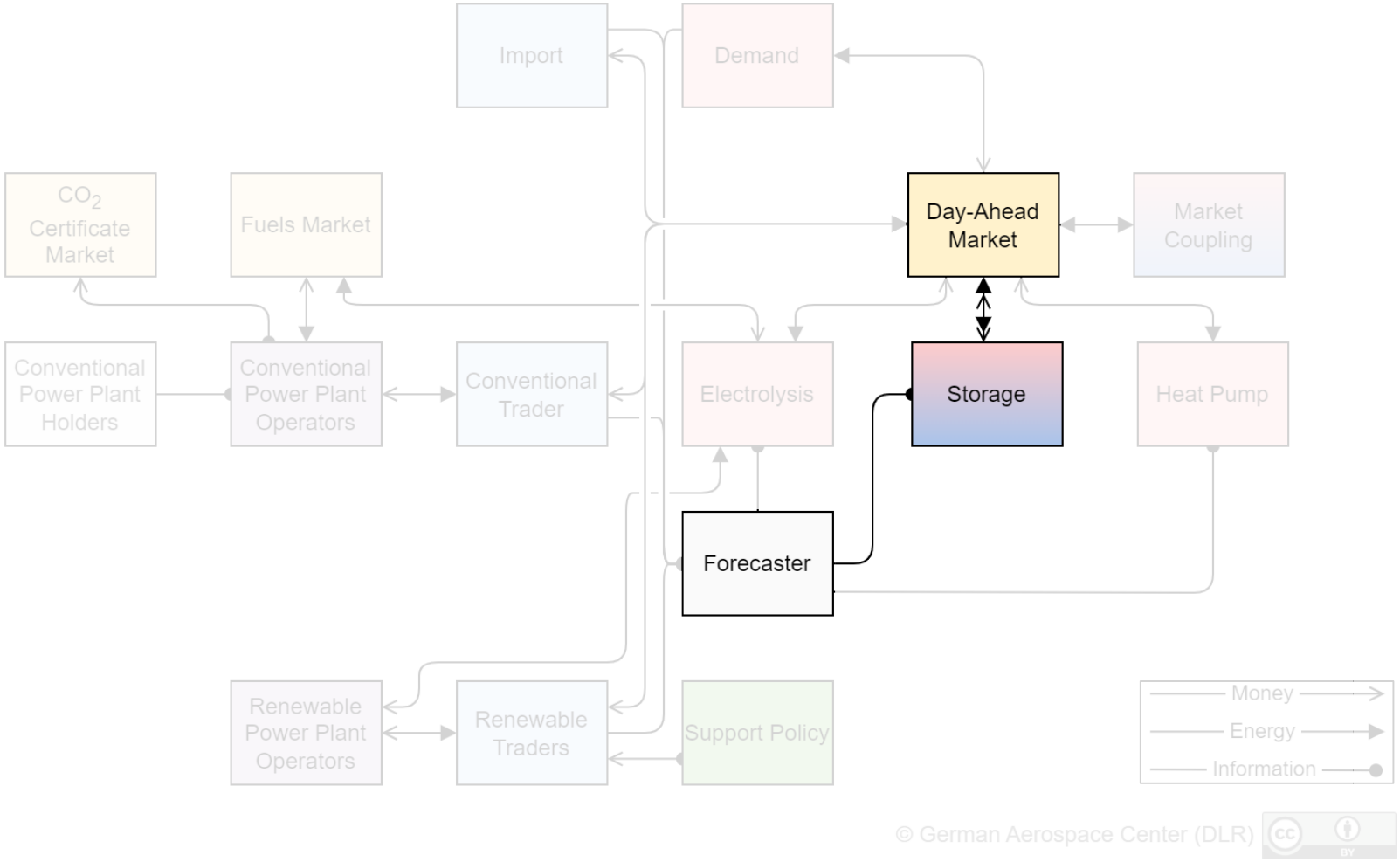

Renewable energy generation in Germany with inflexible load (top) and resulting residual load (bottom) for two weeks in a scenario year 2045





Kochems (2024). 10.14279/depositonce-22008

# AMIRIS
## Open Agent-based Electricity Market Model





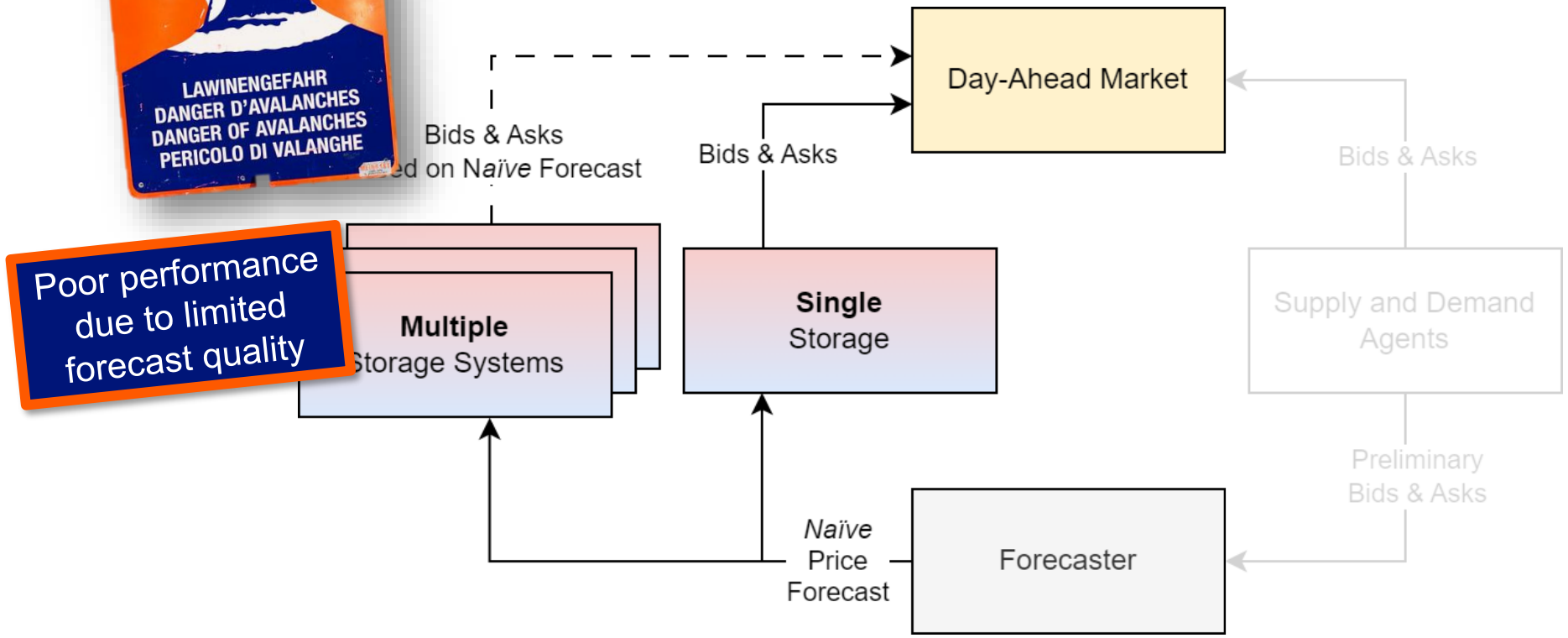

Felix Nitsch, Institute of Networked Energy Systems, 2025-02

Schimeczek et al. (2023a). 10.21105/joss.05041
Schimeczek et al. (2023b). 10.21105/joss.05087
Nitsch et al. (2023a). 10.21105/joss.04958

# Modelling Flexibility Options in AMIRIS

## Limitations of Current Approach


Poor performance due to limited forecast quality





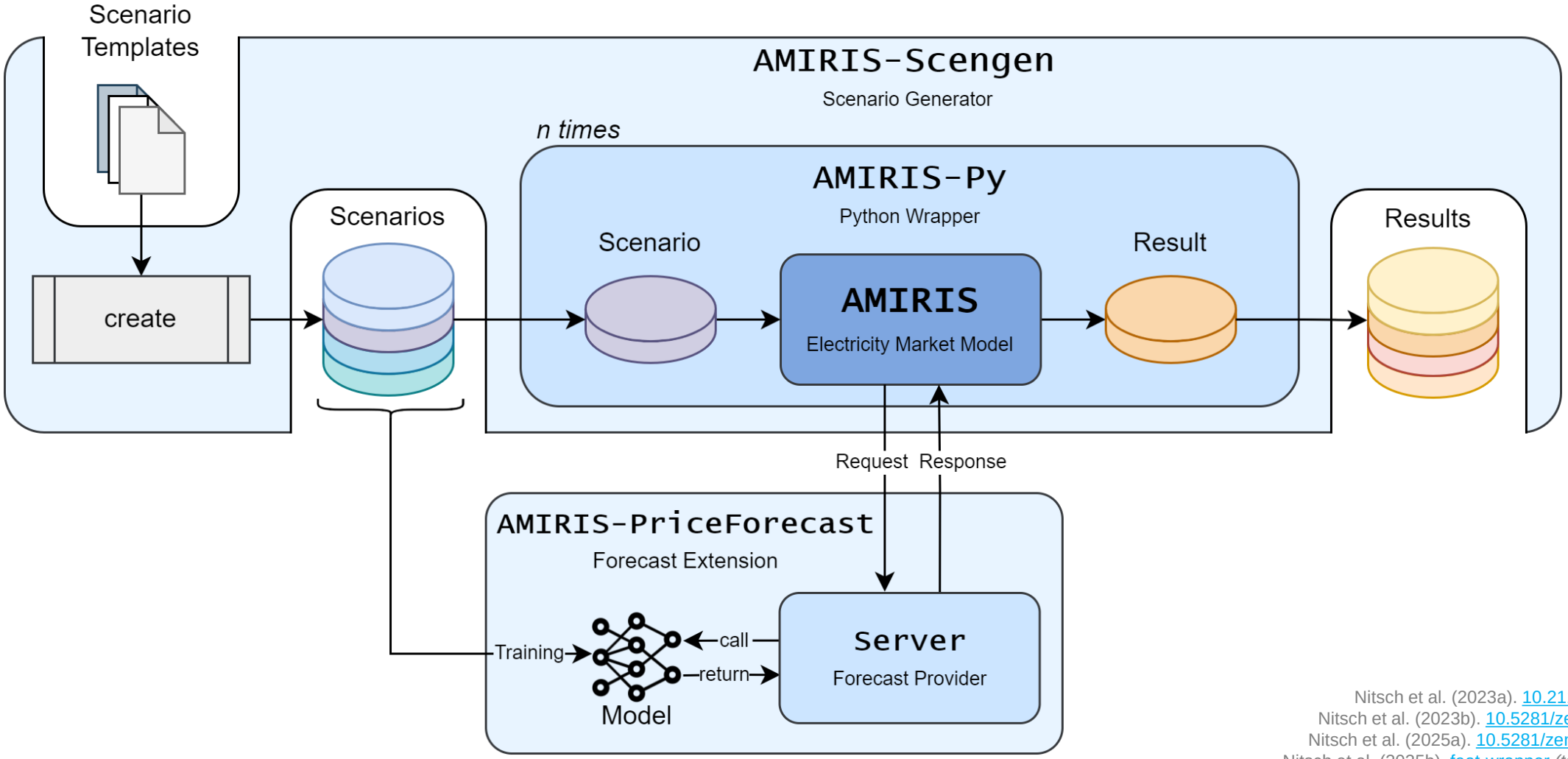





Nitsch et al. (2024). 10.5281/zenodo.10678985

# Model Development and Simulation Setup

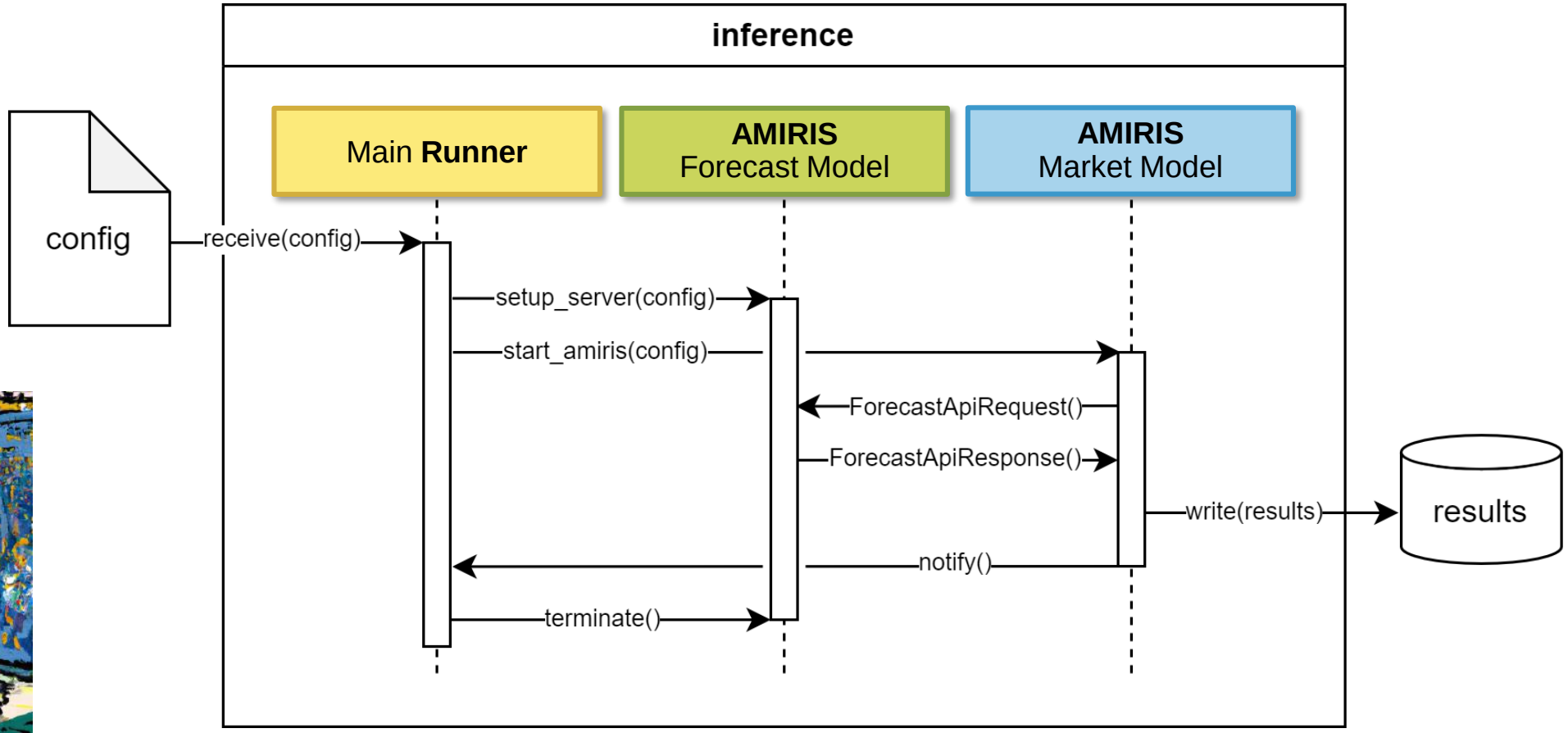
## Enabling Machine-Learning Based Electricity Price Forecasts




Nitsch et al. (2023a). 10.21105/joss.04958
Nitsch et al. (2023b). 10.5281/zenodo.8382789
Nitsch et al. (2025a). 10.5281/zenodo.14907870
Nitsch et al. (2025b). feat-wrapper *(to be published)*
Schimeczek et al. (2023a). 10.21105/joss.05041
Schimeczek et al. (2023b). 10.21105/joss.05087
Schimeczek et al. (2023c). 10.5281/zenodo.14273248

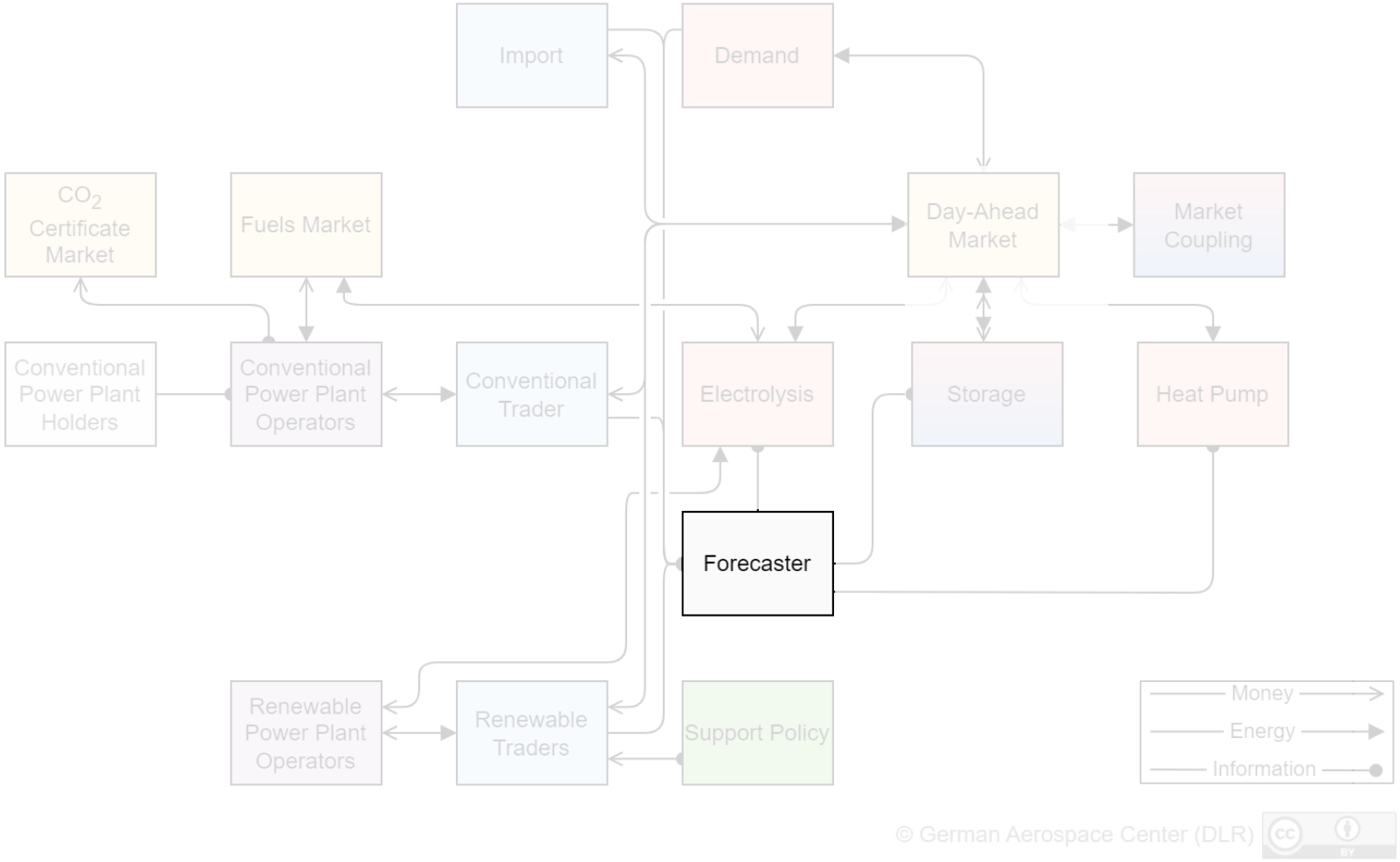
# Connecting AMIRIS to External Forecasting Model

## Coupling using FastAPI




Nitsch et al. (2025a). 10.5281/zenodo.14907870
Nitsch et al. (2025b). feat-wrapper *(to be published)*
Schimeczek et al. (2023a). 10.21105/joss.05041
Schimeczek et al. (2023c). 10.5281/zenodo.14273248

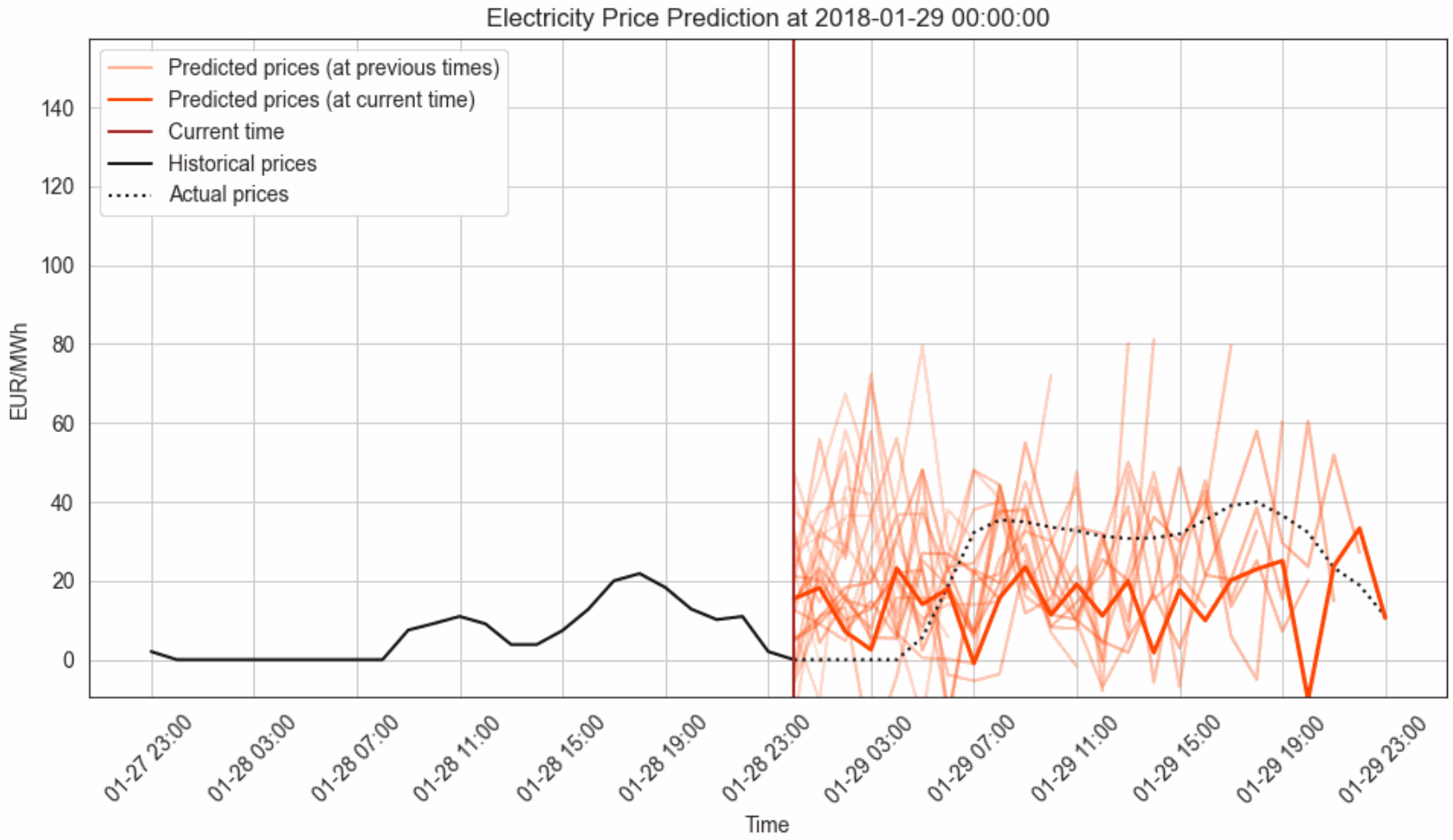
# AMIRIS
## Open Agent-based Electricity Market Model




Schimeczek et al. (2023a). 10.21105/joss.05041
Schimeczek et al. (2023b). 10.21105/joss.05087
Nitsch et al. (2023a). 10.21105/joss.04958

# Electricity Price Forecasts

## Accuracy – 10 Epochs



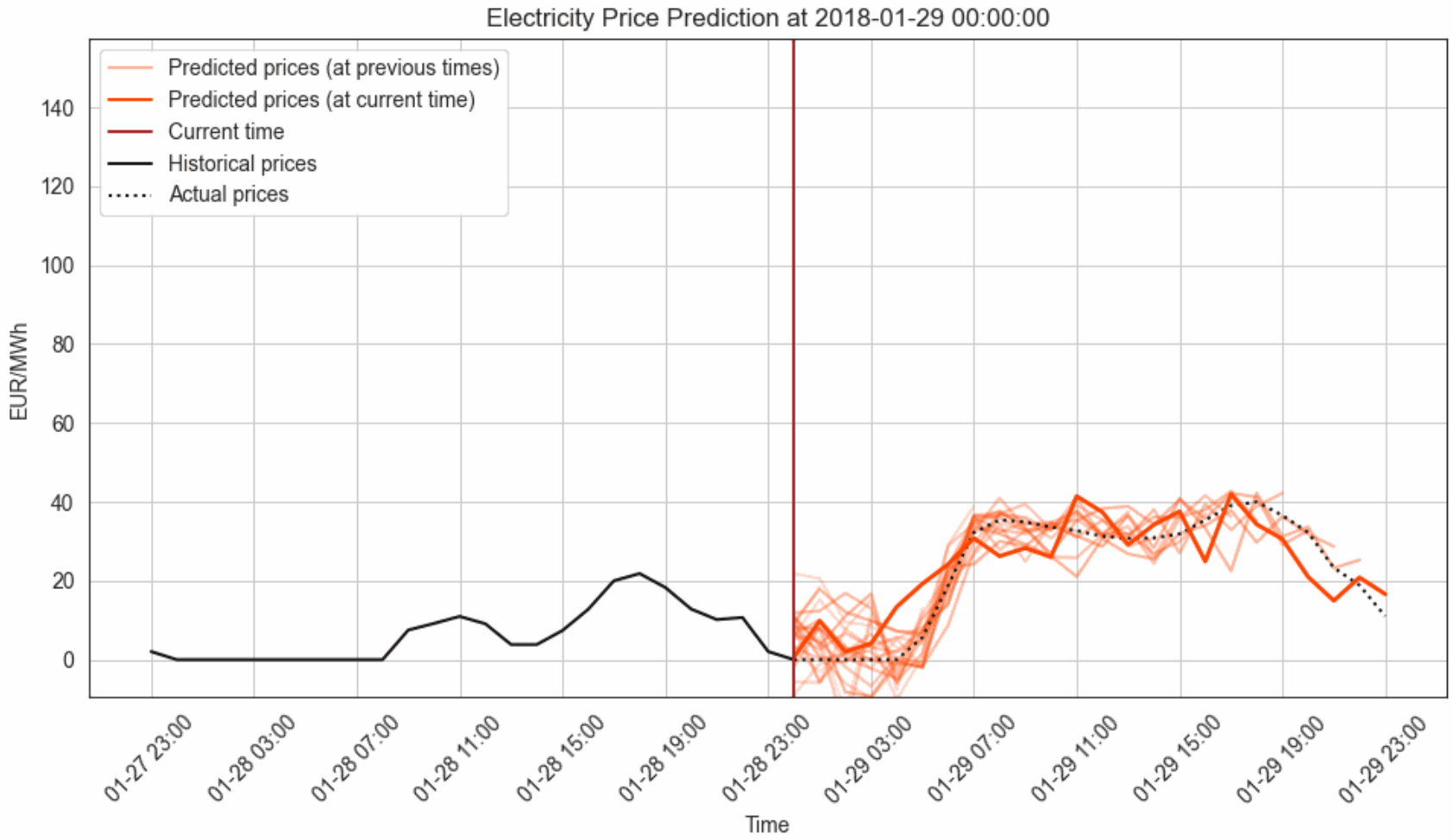



Felix Nitsch, Institute of Networked Energy Systems, 2025-02

Model used: TFT 10-Epochs 4-LSTM 16-Hidden 24-Lags [Residual Load, Electricity Prices]

# Electricity Price Forecasts

## Accuracy – 30 Epochs



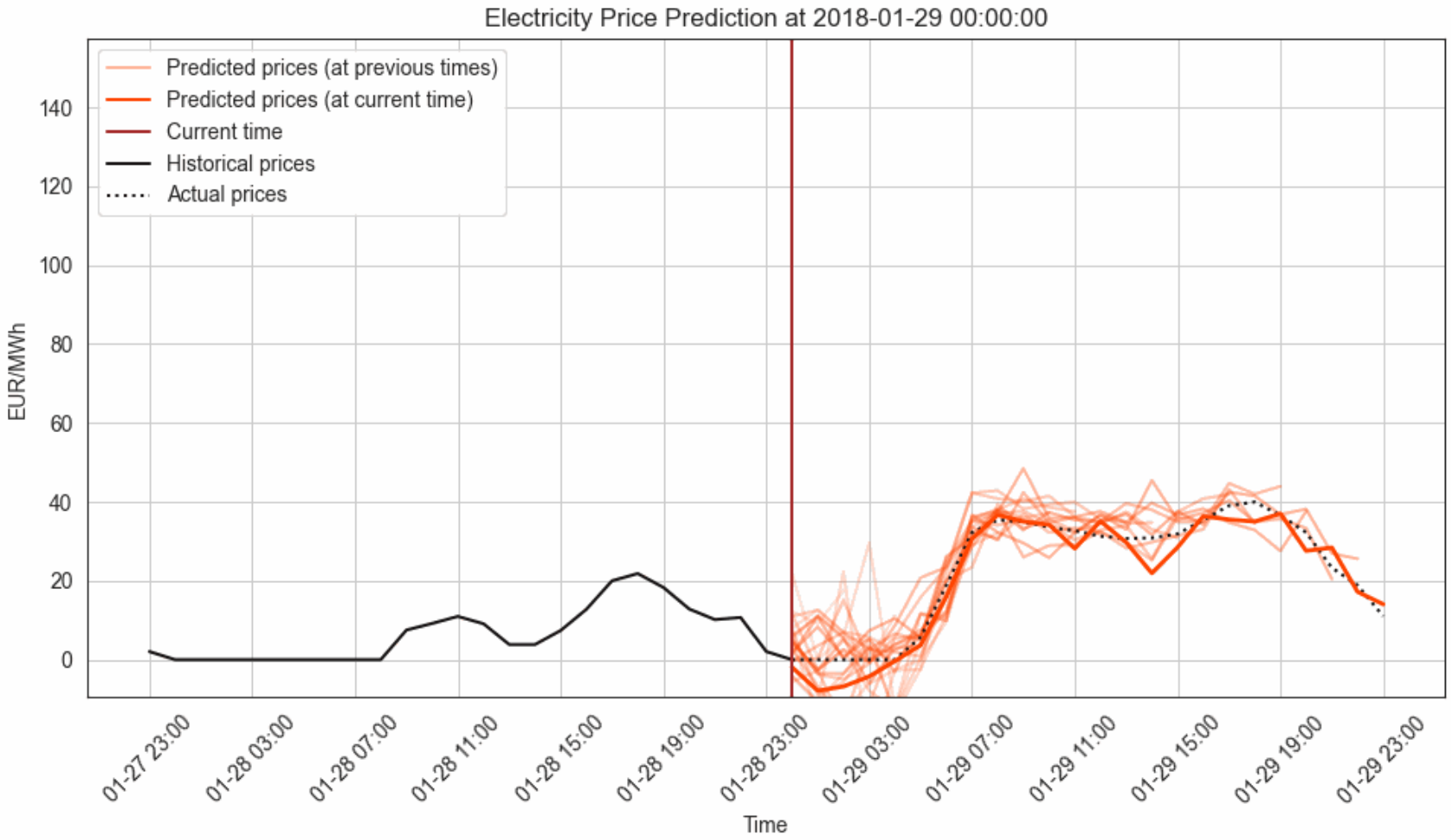



Felix Nitsch, Institute of Networked Energy Systems, 2025-02

Model used: TFT 30-Epochs 4-LSTM 16-Hidden 24-Lags [Residual Load, Electricity Prices]

# Electricity Price Forecasts

## Accuracy – 50 Epochs





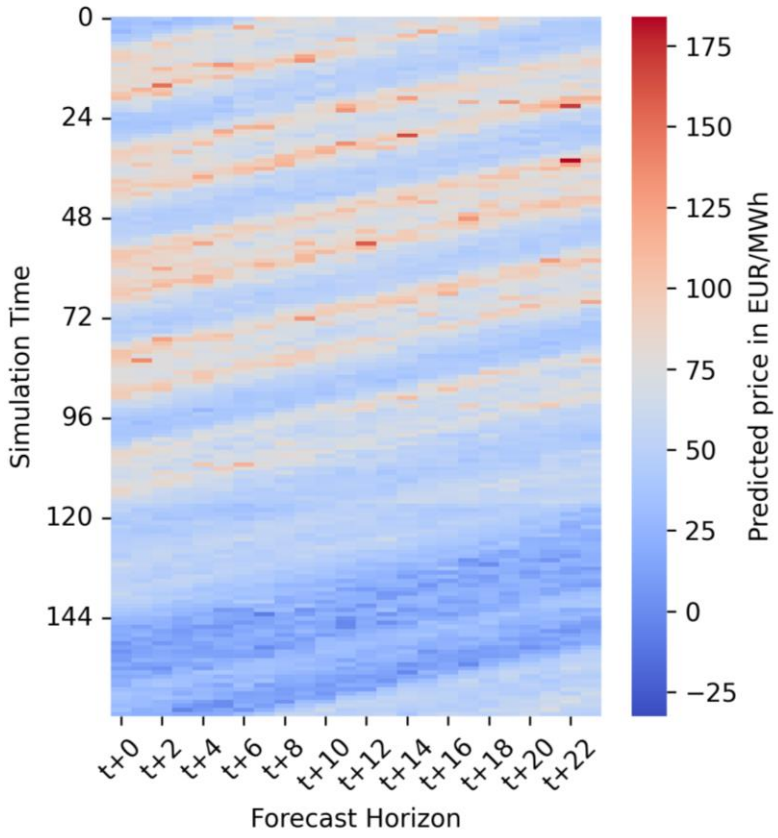

Felix Nitsch, Institute of Networked Energy Systems, 2025-02

Model used: TFT 50-Epochs 4-LSTM 16-Hidden 24-Lags [Residual Load, Electricity Prices]

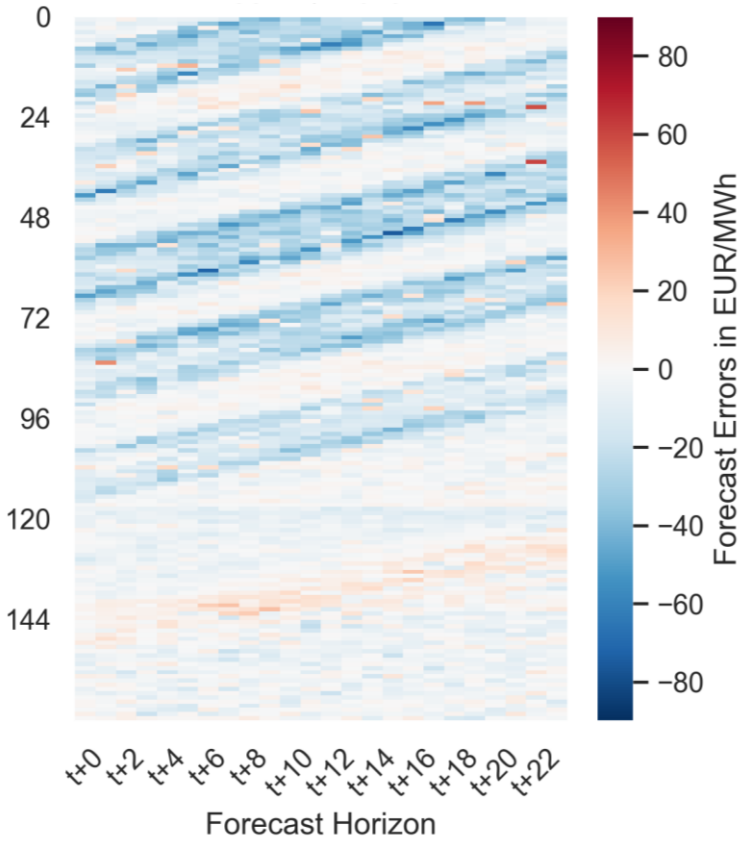
# Electricity Price Forecasts

## Accuracy – Forecasted Price

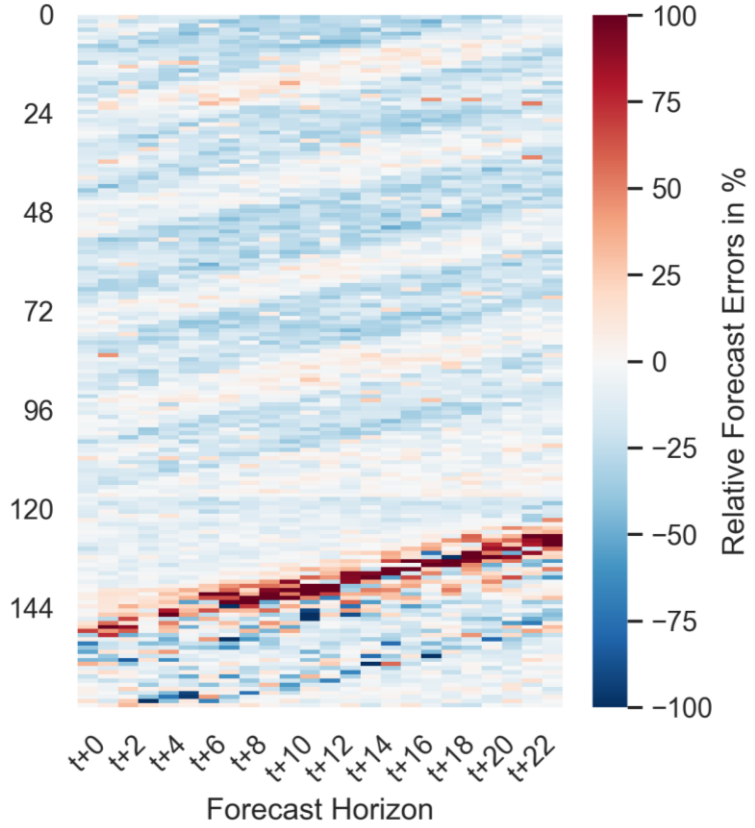
### Forecasted Price




### Absolute Forecast Error




### Relative Forecast Error

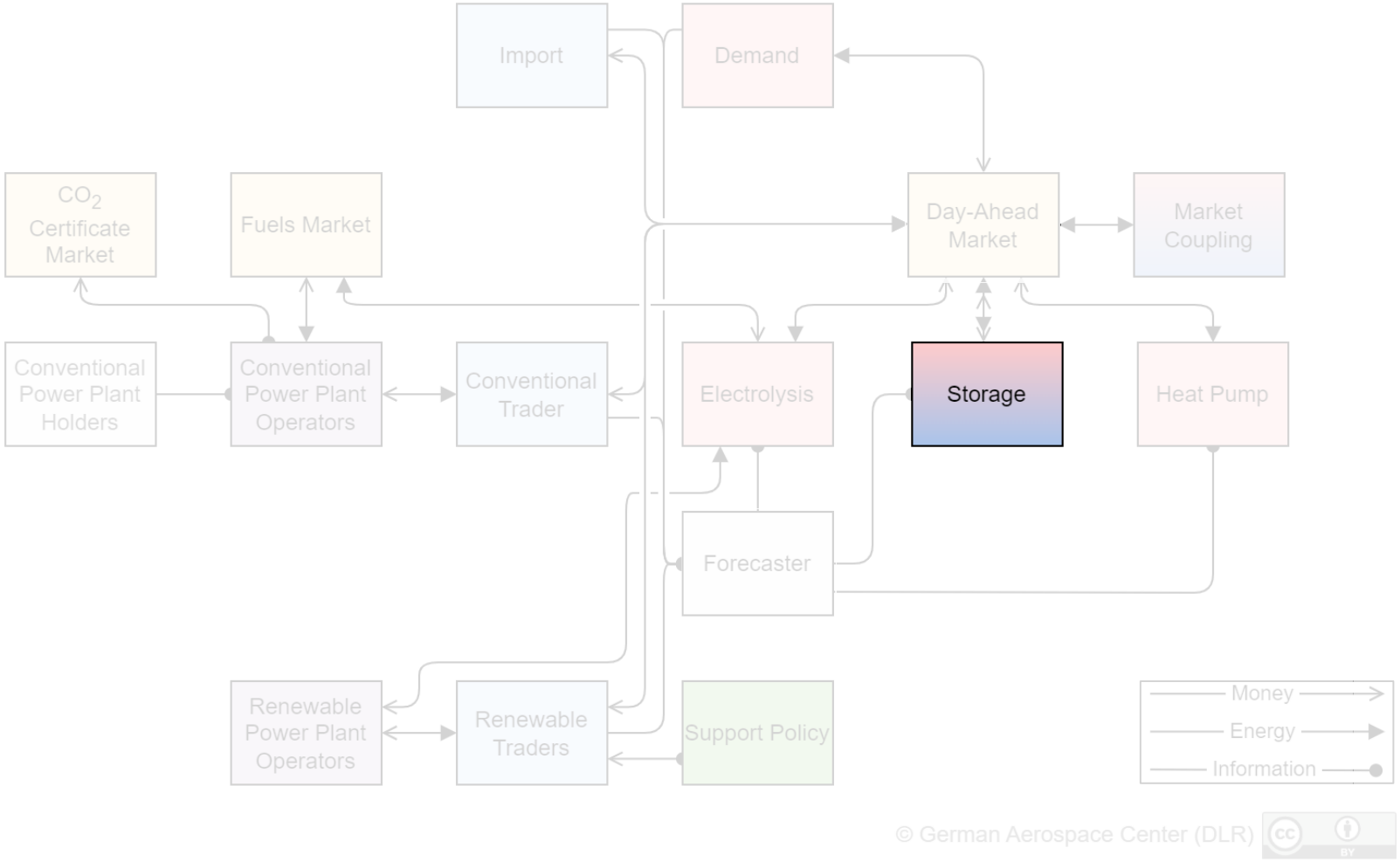





Felix Nitsch, Institute of Networked Energy Systems, 2025-02

Model used: TFT 4-LSTM 16-Hidden 24-Lags [Residual Load, Electricity Prices]

# AMIRIS
## Open Agent-based Electricity Market Model




Schimeczek et al. (2023a). 10.21105/joss.05041
Schimeczek et al. (2023b). 10.21105/joss.05087
Nitsch et al. (2023a). 10.21105/joss.04958

# State of Charge

## Impact of Forecast Type & Storage Strategy

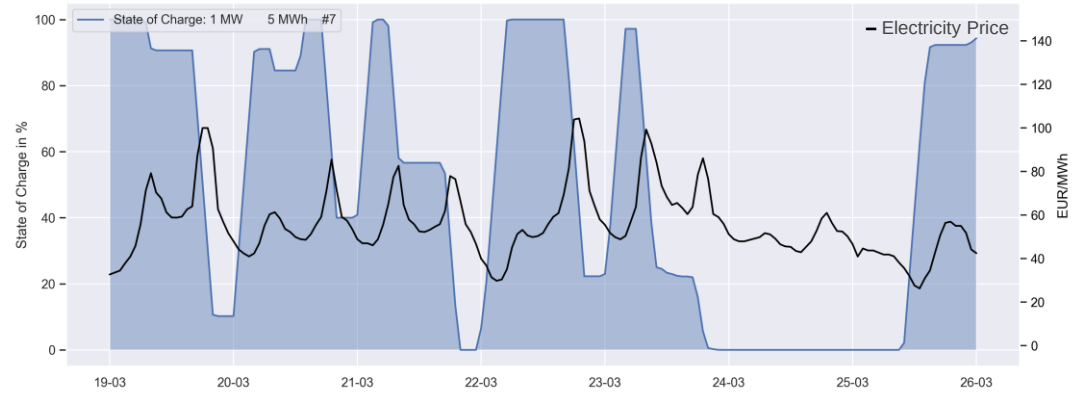
**Electricity Price Forecast Type**

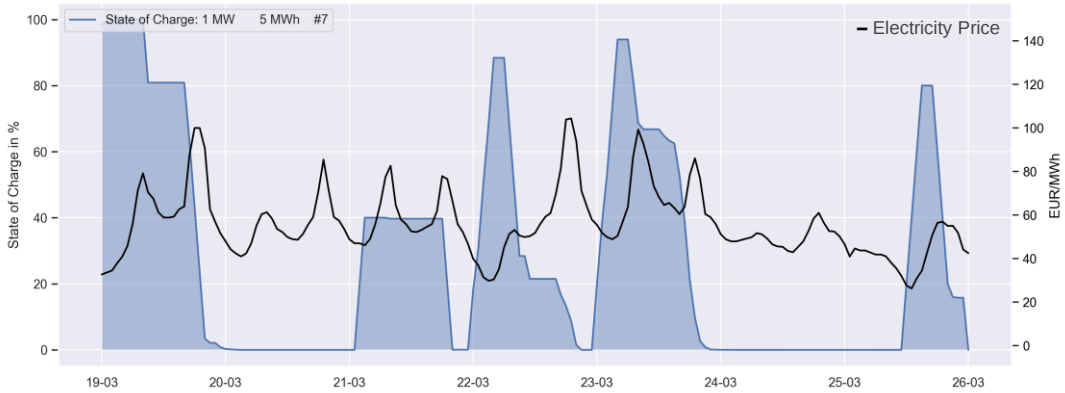
**Storage Strategy**

### Perfect Foresight

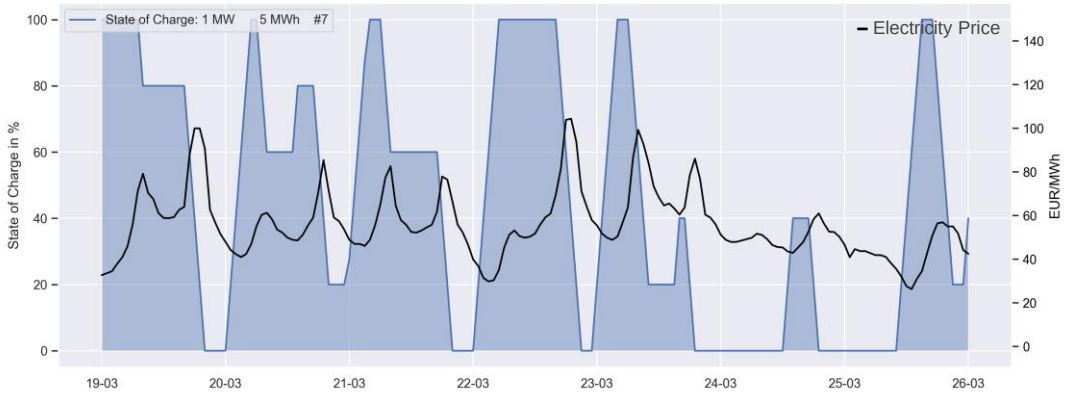
### Neural Network Based Forecast

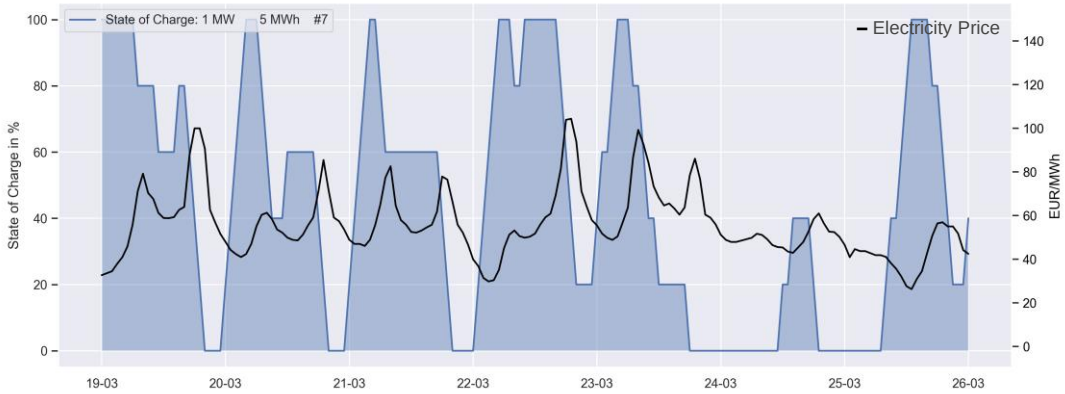
Risk-Averse




Risk-Affine








Storage: single 1MW/5MWh

# Storage Activity

## Impact of Forecast Type & Storage Strategy

**Electricity Price Forecast Type**

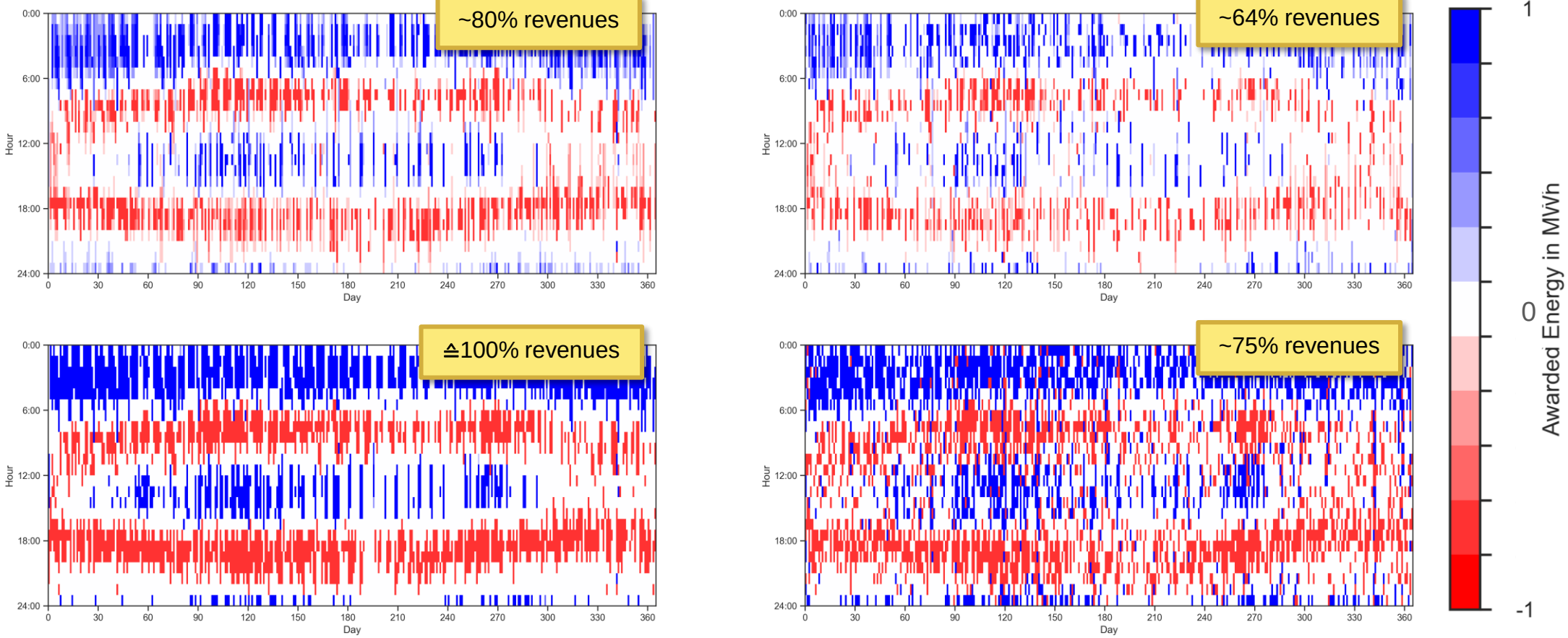
**Storage Strategy**

Perfect Foresight

Neural Network Based Forecast

Risk-Averse

Risk-Affine



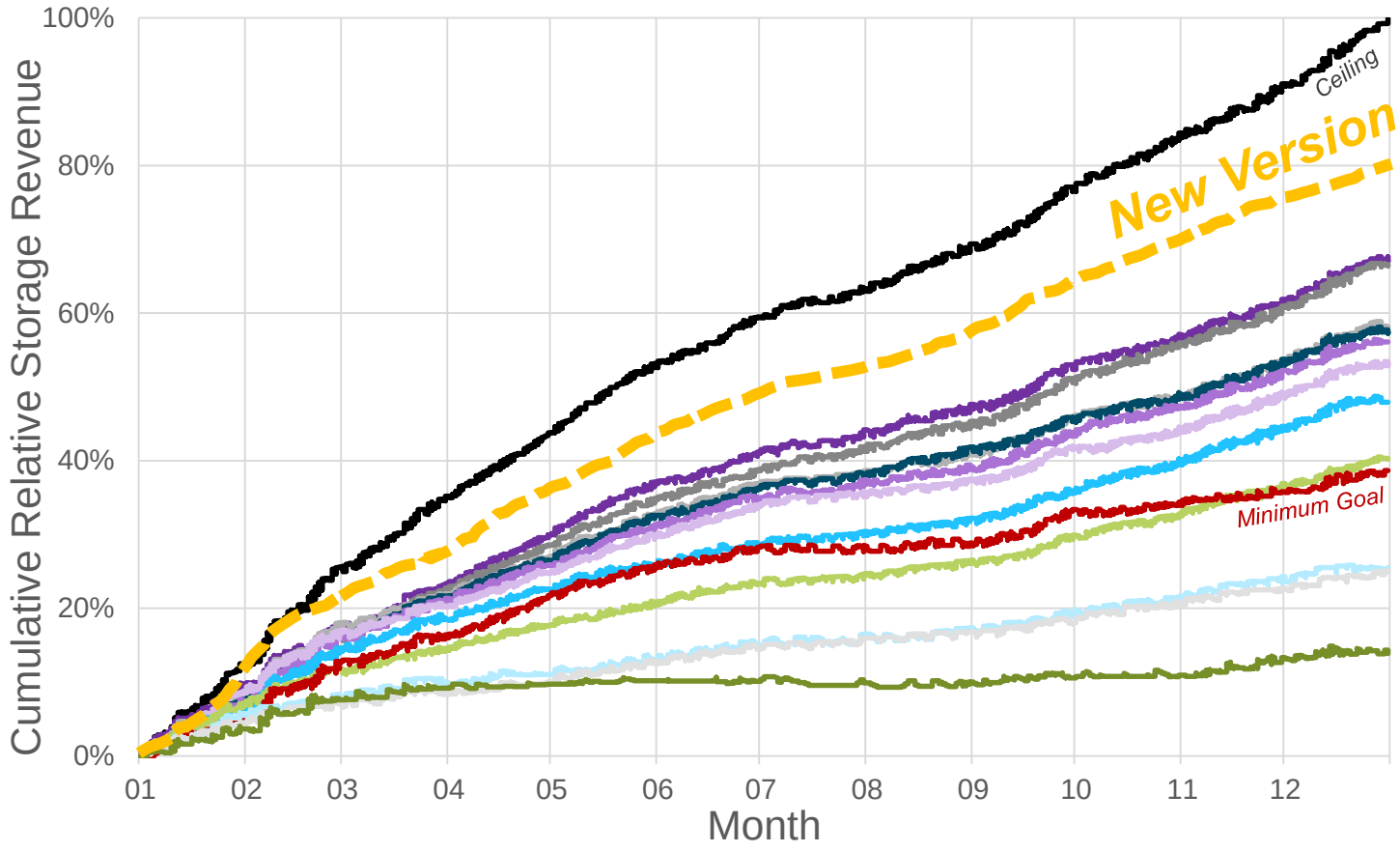





Storage: single 1MW/5MWh

# Revenue Impact of the Model Used

*The more complex the better?*




| Model | Training Effort |
|---|---|
| Perfect Foresight | *n.a.* |
| TFT 100-Epochs 4-LSTM 32-Hidden | |
| TFT 100-Epochs 4-LSTM | |
| TFT 10-Epochs 4-LSTM | |
| TFT 100-Epochs | |
| TFT 10-Epochs 4-LSTM 32-Hidden | |
| TFT 10-Epochs 4-LSTM 8-Hidden | |
| TFT 10-Epochs | |
| TFT 10-Epochs 8-LSTM | |
| Naive TimeShift24 | *n.a.* |
| TFT 1-Epoch | |
| TFT 1-Epoch 4-LSTM | |
| TFT 10-Epoch 4-LSTM 48-Lags | |

**TFT Default:** 1-LSTM 16-Hidden 24-Lags

Low | Medium | High

"New version" uses residual load as covariate



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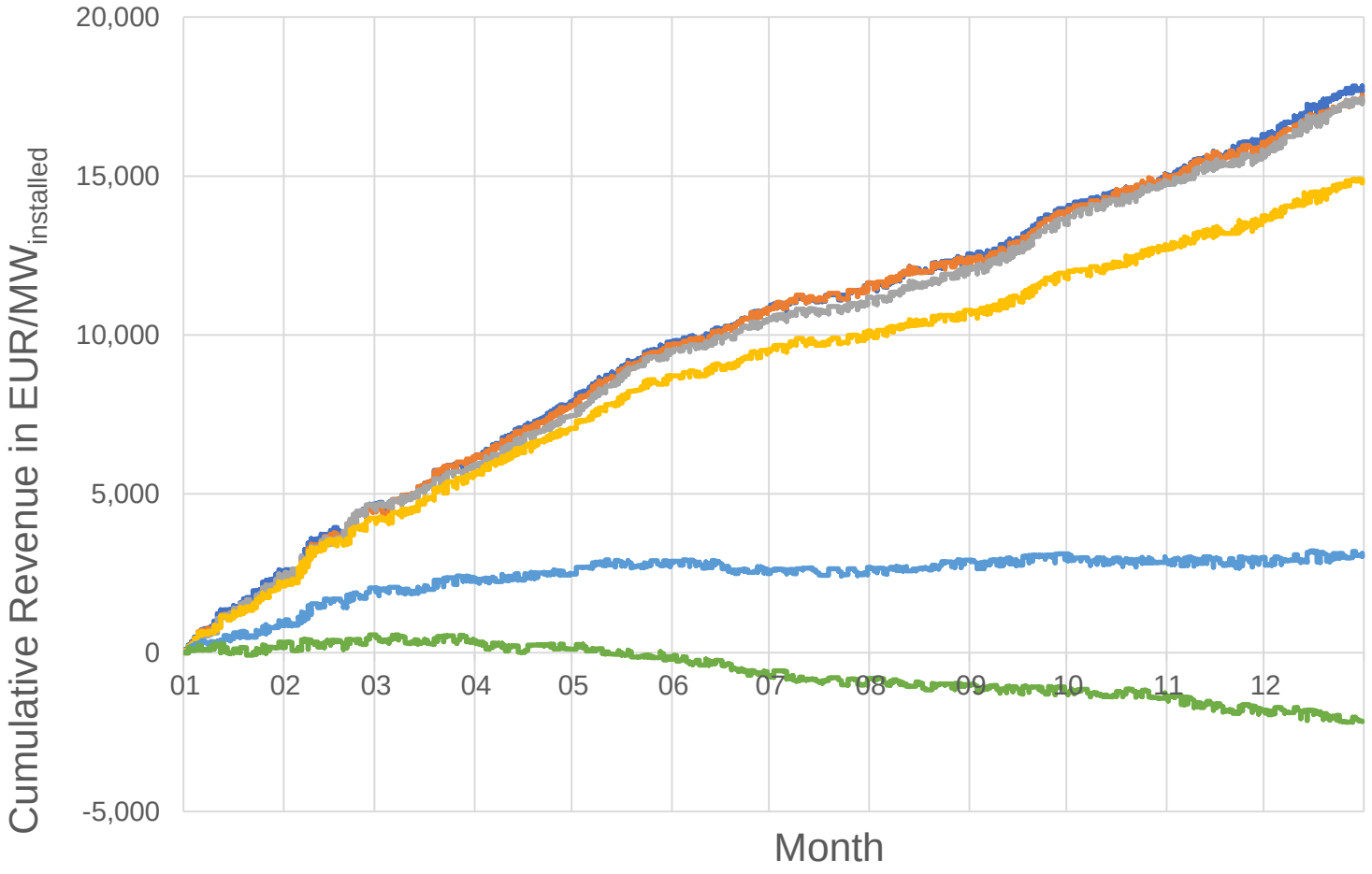
Storage: single 1MW/5MWh using multi-median strategy

# Revenue by Storage Size

## Too big ~~to fail~~ for success




**Storage Power**

- 1MW
- 10MW
- 100MW
- 1.000MW
- 5.000MW
- 10.000MW

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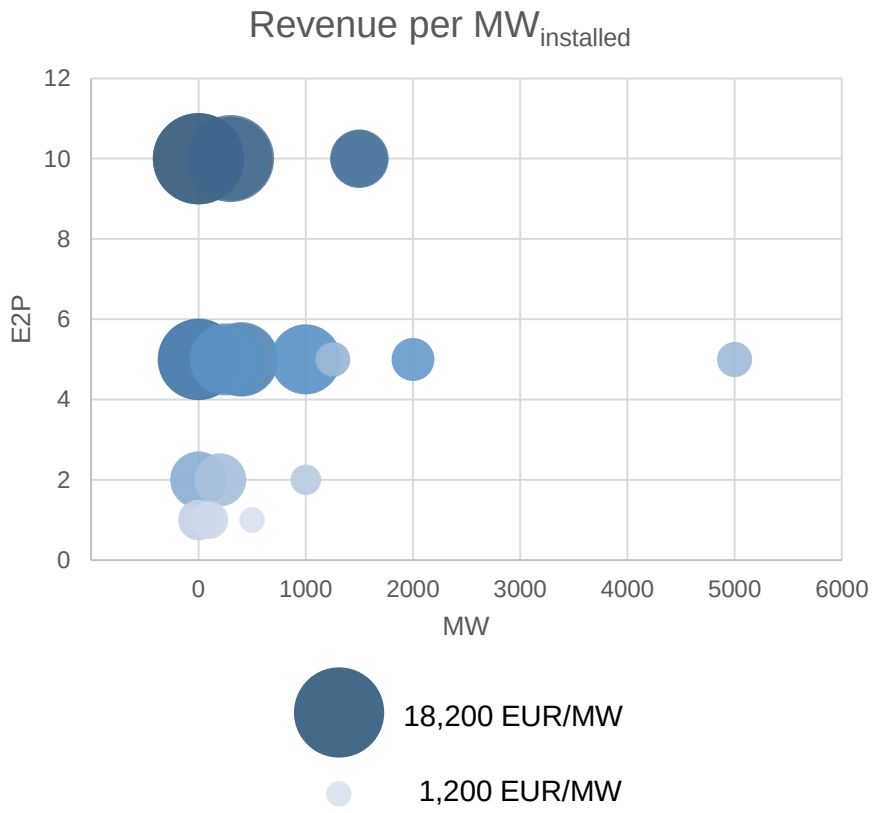
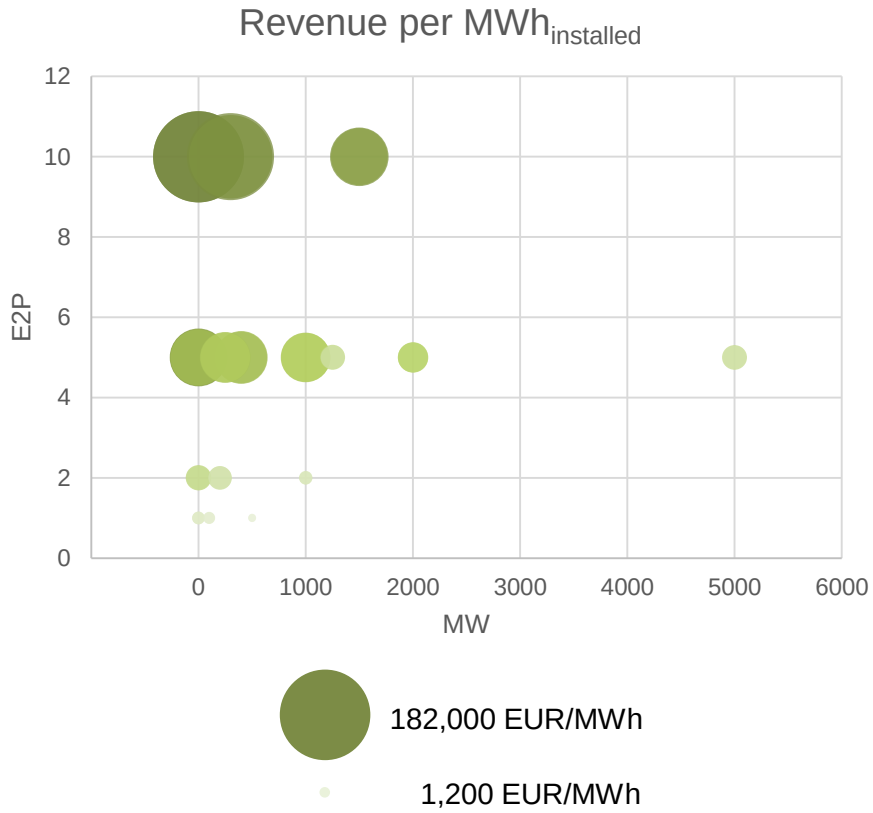
Model used: TFT 100-Epochs 4-LSTM 32-Hidden 24-Lags

# Revenue by Storage Specification

## Power vs. capacity



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Model used: TFT 100-Epochs 4-LSTM 32-Hidden 24-Lags

# Discussion
## Novelty and Limitations

### Strengths

- Market driven economic evaluation of storage potential
- Fully automated open pipeline
- Accurate and flexible forecasts at runtime
- Fast execution with low overhead

### Weaknesses

- No additional revenue streams besides Day-Ahead market (DAM)
  →DAM considered as benchmark/indicator
- Uncertainty in system design
  →Transparent communication of assumptions
  →Open modelling setup and data publication

# Conclusions

- Machine learning based electricity price forecasts with **high accuracy**
- **Modular** integration of forecasts in agent-based electricity market simulation
- **Revenue analysis** of storage systems

# Outlook

- ARIADNE scenario parameterisation and analysis https://ariadneprojekt.de/
- Competition among heterogeneous storage systems
- Publication of the presented tool chain

**Acknowledgements:** Valentin Bertsch, Kristina Nienhaus on behalf of the Energy Economics Group

**Contact:** Felix Nitsch, felix.nitsch@dlr.de, German Aerospace Center, Institute of Networked Energy Systems, Energy Systems Analysis

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# APPENDIX

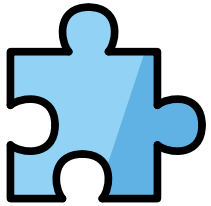
# AMIRIS
## Following FAIR4RS Principles

### Findable

- Website
- DOI
- Wikipedia
- COMSES
- HECI
- OEP
- openmod

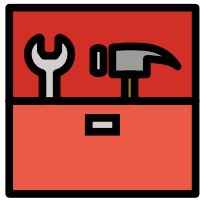
### Accessible

- GitLab
- PyPI
- Zenodo



### Interoperable

- API
- Workflow tools
- CSV
- YAML



### (Re-)usable

- Apache 2.0
- REUSE
- Wiki
- Javadoc
- Win/Mac/Linux
- Scalable (H)PC



## Key Indicators

### Users

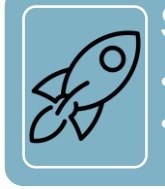
- 25 confirmed external user
- 9 external contributions

### PhD candidates

- 7 internal
- 6 external

### Visibility

- 25k views on Wikipedia
- 16k views on openmod



### Software

- 35 releases
- 27k downloads

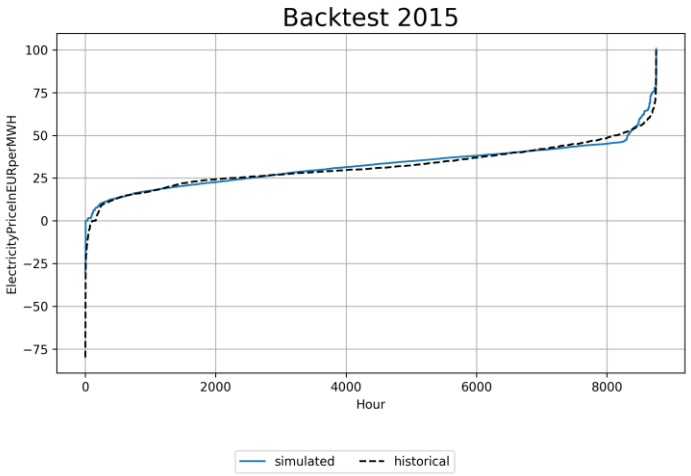


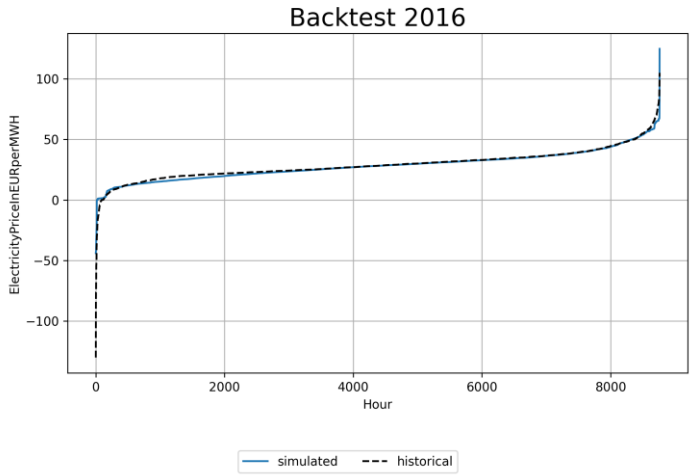


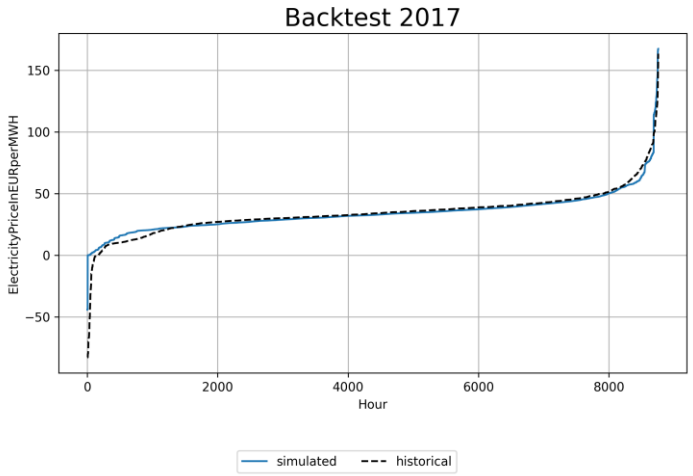
Barker et al. (2022). 10.1038/s41597-022-01710-x

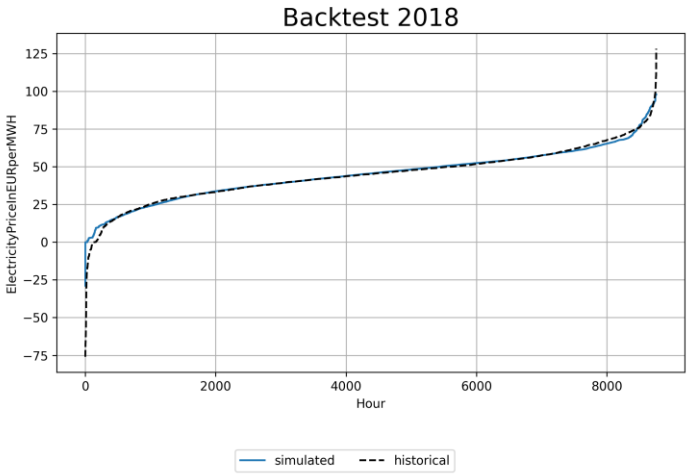
# AMIRIS Backtesting 2015 – 2019

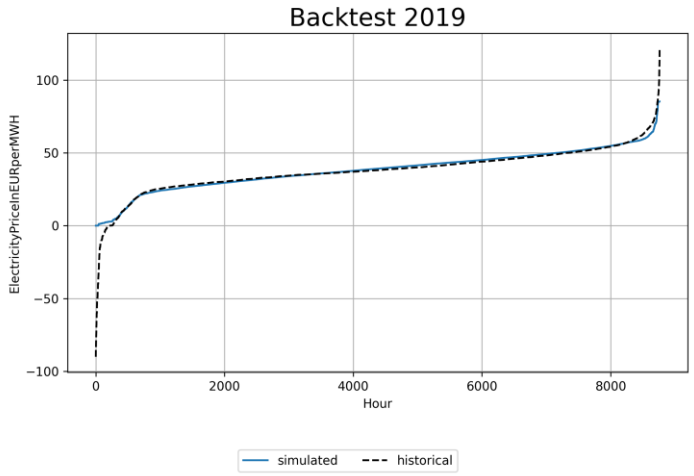
## Price duration curves




- Model parameterization using open data only
- Benchmarking and convenient scenario setup
- Data available in open [AMIRIS example repository]



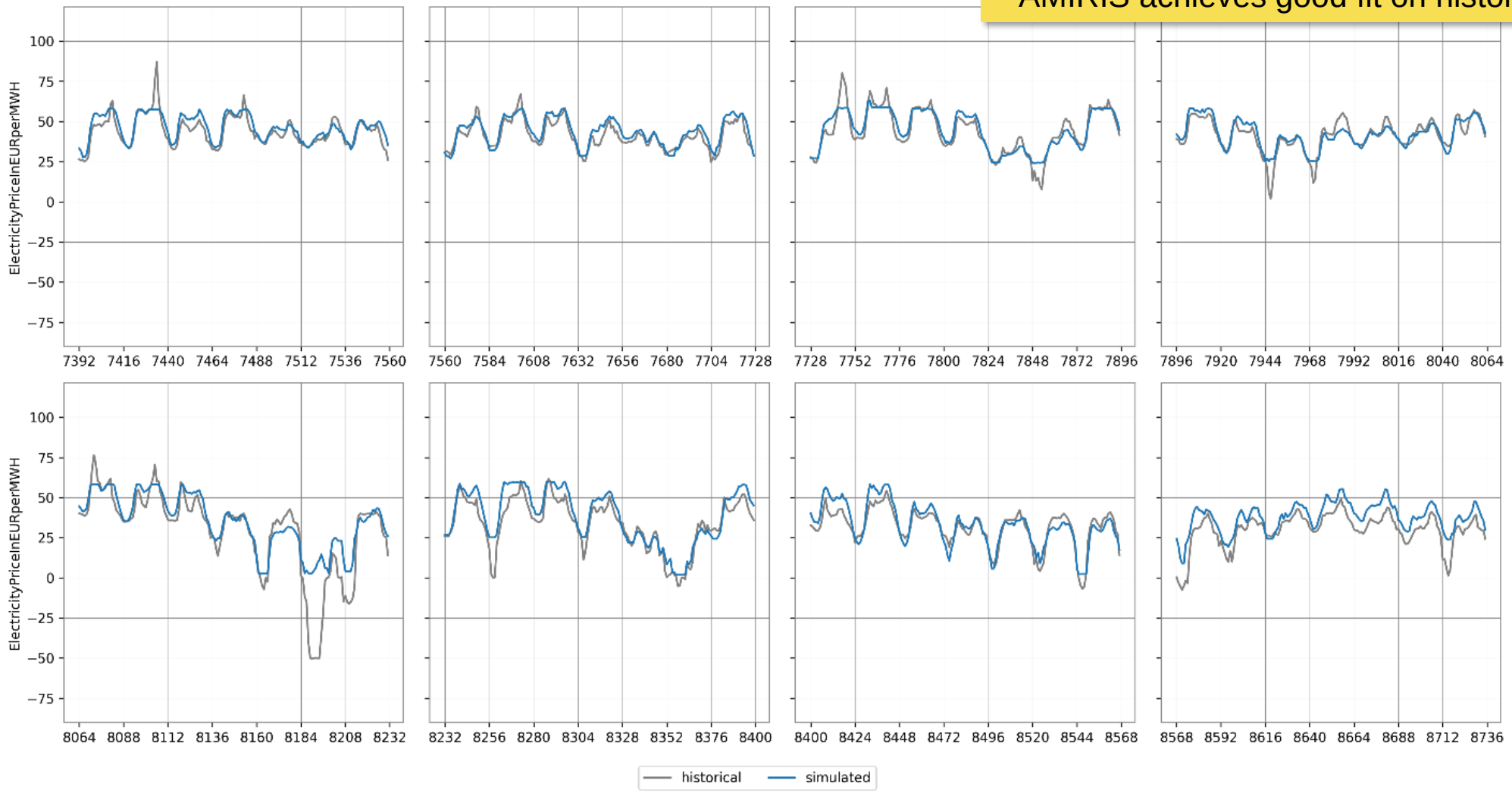
Christoph Schimeczek, Institute of Networked Energy Systems

Nienhaus et al. (2023). 10.5281/zenodo.7789049

# AMIRIS Backtesting 2015 – 2019

## Exemplary weeks in 2019

AMIRIS achieves good fit on historical data






Christoph Schimeczek, Institute of Networked Energy Systems

Nienhaus et al. (2023). 10.5281/zenodo.7789049

# Imprint

| | |
|---|---|
| **Topic** | ML-Based Price Forecasts<br>in the open electricity market model AMIRIS |
| **Date** | 2025-02 |
| **Author** | Felix Nitsch |
| **Institute** | Institute of Networked Energy Systems |
| **Credits** | DLR (CC BY-NC-ND 3.0)<br>except stated otherwise |

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