Using Open Access Power Plant Data for Stochastic Availability Modelling

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Introduction

Uncertainty regarding available generation capacities increases and becomes more relevant:

- Reduction in installed conventional power plant capacities (coal phase out, nuclear phase out)
- Expected increase in demand (electrification of heating and transport) and its increasing weather dependence
- Less dispatchable generation capacities

Assessment of the quality of power plant outage data of the **ENTSO-E Transparency Platform**

- Highlight key descriptive statistics and data inconsistencies

Development of a **non-homogenous semi-Markov model** to simulate the availability of generation capacities

- Considering seasonal, technology and regional effects
- Empirical parameterization

Background and research approach

Modeling of generation availability

Capacity availability distribution

- Stochastic distribution of system availability derived by recursive convolution of (time-dependent) unavailability probabilities of individual power plants
  - Bucksteeg (2019), Nolting et al. (2020)

Markov models

- Temporal dependency modeled considering stochastic and deterministic effects. Mostly used for forced outages
  - Pievatolo et al. (2004), Billinton and Li (2007), van Casteren et al. (2000)

Deterministic approaches for planned availability

- Periodic maintenance intervals optimized without consideration of stochastic effects.
  - Guerrero-Mestre et al. (2020),

Empirical models for generation adequacy assessment

Gils et al. (2018)

- **Focus**: Stochastic hourly power plant availability for security of supply assessment based on historical data
- **Method**: Mean-reversion Jump-diffusion model
- **Data**: German data for 2013 & 2014 from EEX transparency platform
- **Highlights**: Simulations reflect statistical behavior of limited available data

Guerrero-Mestre et al. (2020)

- **Focus**: Uncertainty of conventional generation availability for large-scale generation adequacy assessment based on publicly available data
- **Method:** Homogenous Markov model
- **Data:** ENTSO-E Transparency Platform 2015 – 2017; World Energy Council (2010)
- **Highlights:** Data gaps and inconsistencies affect analysis

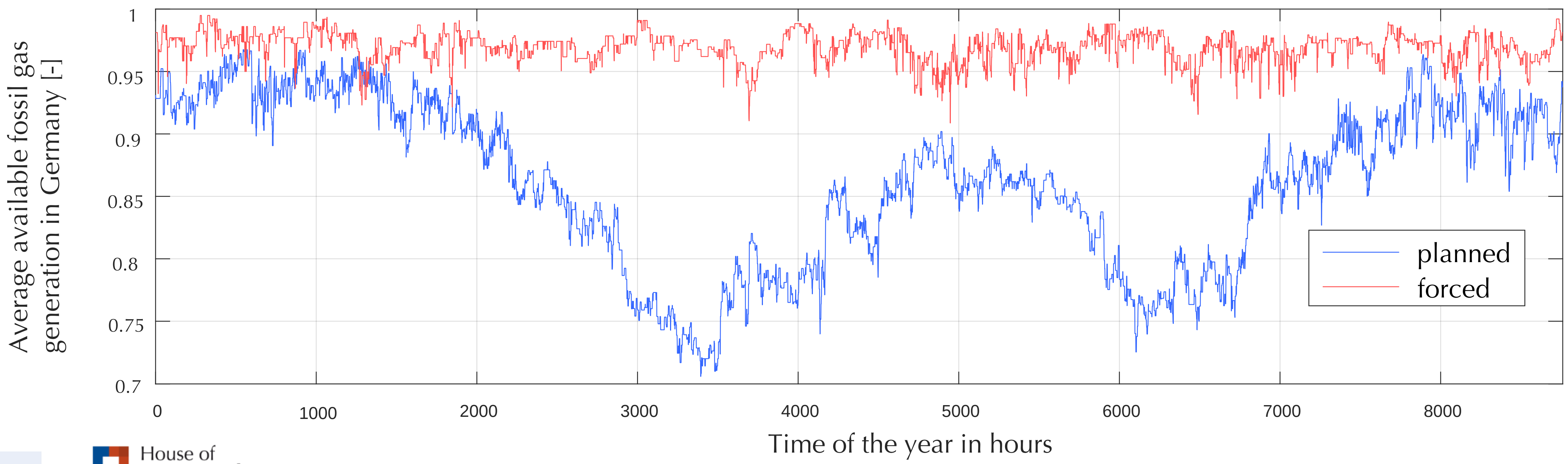
Research gap

- Simulate forced & planned unavailabilities unit-wise using Markov model
- Use large, publicly available data set for model parametrization

Data set – Power plant outages

Power plant outages from 2018 to 2021 processed to available generation per country (source: ENTSO-E Transparency Platform)

- Planned and forced availability differs in seasonal effects, duration and frequency. All depending on power plant specific characteristics



semi-Markov Model – The general form

Model the availability of a power plant with the semi-Markov process $Av_{t,u}$ given by

- system states S with state space $\mathcal{M} = \{1,2,3\}$, where $S_n \neq S_{n-1}$
- jump times J_n, n $\in [0, T]$, where $0 = J_0 < J_1 < \cdots < J_n \cdots < J_T$
- holding times $\tau = J_n - J_{n-1}$

such that $Av_{t,u} = \begin{cases} 0 & if\ S_n \in \{2,3\} \\ 1 & otherwise \end{cases}$ for $t \in [J_n, J_{n+1}]$

State transitions are defined by

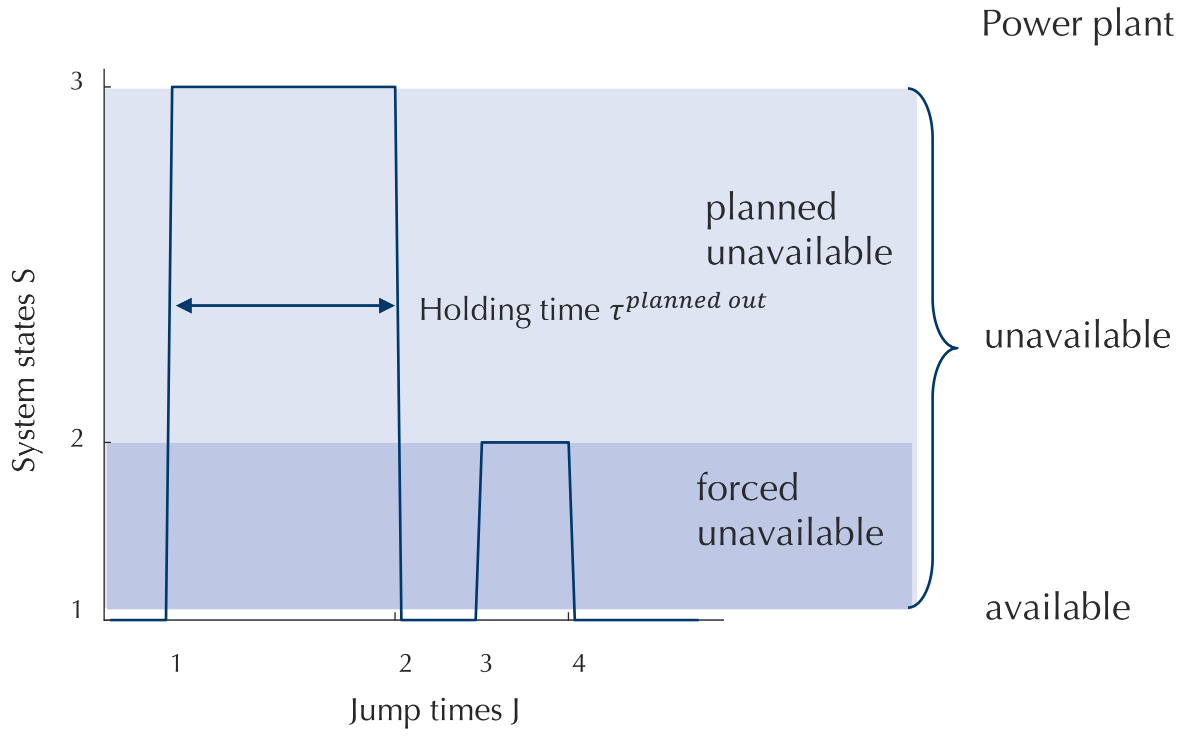
- cumulative distribution

$$F_{ij}(\tau) = \mathbb{P}[J_{n+1} - J_n \leq \tau |\ S_n = i, S_{n+1} = j]$$

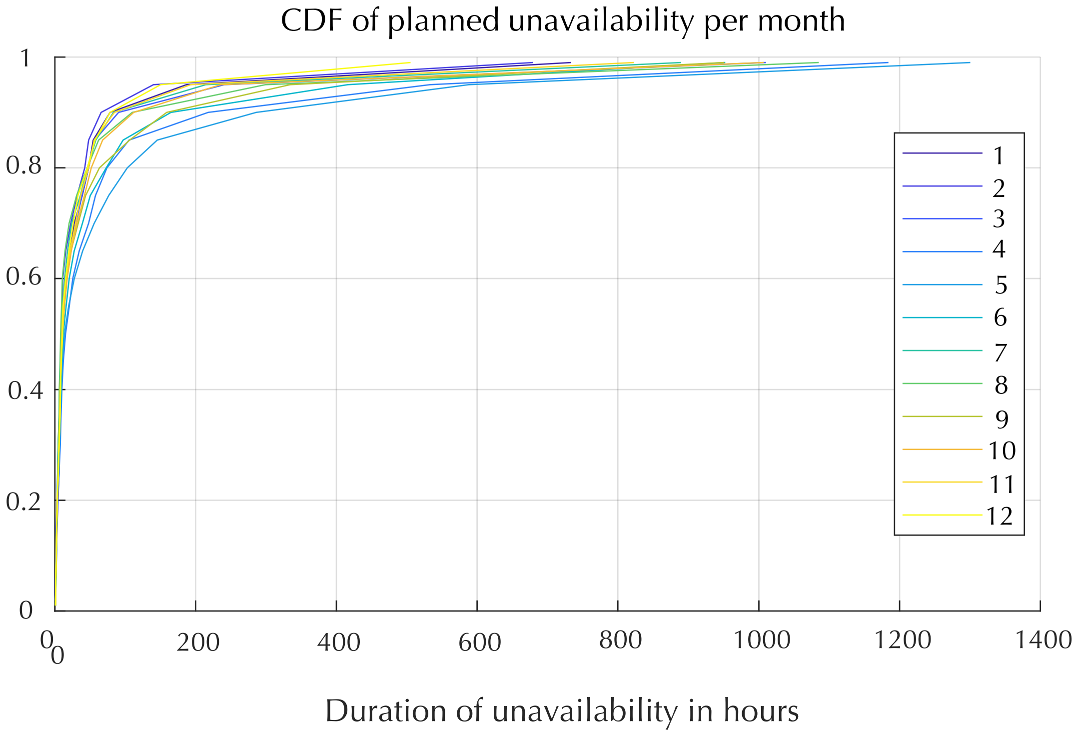
- transition probability matrix $\boldsymbol{P}$ with elements

$$\boldsymbol{p}_{ij} = \mathbb{P}[S_{n+1} = j \mid S_n = i]$$

for $i \neq j$ and $i, j \in \mathcal{M}$, $t \in [0, T]$



semi-Markov Model – Holding time distribution



- Example here for German fossil gas power plants
- Duration of planned outages increases during summer

Quantile regression function for holding time distribution

$$f_q(X_{t,u}, \beta_q) = \exp\Big(\underbrace{\beta_{0,q} + \beta_{5,q}\mathcal{T}_u}_{\text{type of outage}} + \underbrace{\sum_{i=1}^{11} \beta_{9+i,q}\mathcal{M}_t}_{\text{periodical seasonal effects}}$$

$$\underbrace{+ \sum_{i=1}^{4} \beta_{20+i,q}\mathcal{R}_u + \sum_{i=1}^{4} \beta_{24+i,q}C_u + \sum_{i=1}^{4} \beta_{28+i,q}PT_u}_{\text{effects of power plants characteristics}}\Big)$$

Dummies for

$\mathcal{T}_u$ type of unavailability

$\mathcal{M}_t$ month-of-the-year

$\mathcal{R}_u$ country of origin

C_u installed capacity

PT_utechnology

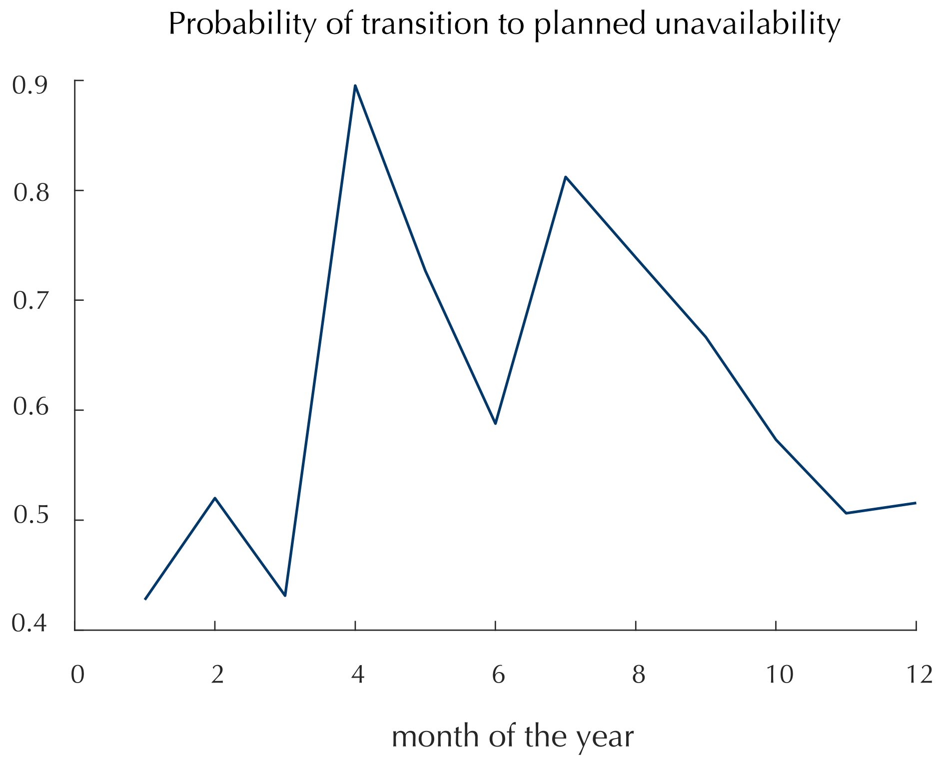
semi-Markov Model – Transition probability

Probability of transition from state *available* to *planned unavailable* based on the **M**ean **T**ime **t**o **R**epair in month m and region r

$$p_{1,3}^{m,r} = \frac{MTtR_{1,3}^{m,r}}{MTtR_{1,3}^{m,r} + MTtR_{1,2}^{m,r}}$$

Following Barbu and Limnios (2009), we assume

- no transitions to same state
- no transitions between states *forced unavailable* and *planned unavailable*



Transition probabilities reflect seasonal effects

- Planned long (& rare) unavailabilities mostly before resp. after winter resulting in high transition probability to planned unavailability in these months

Data set – Overview and descriptive statistics

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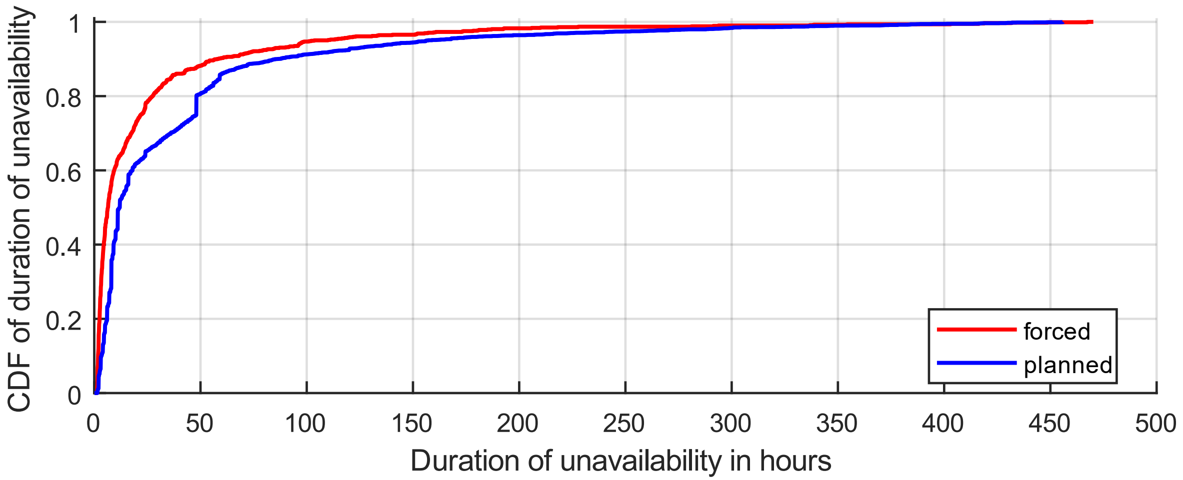
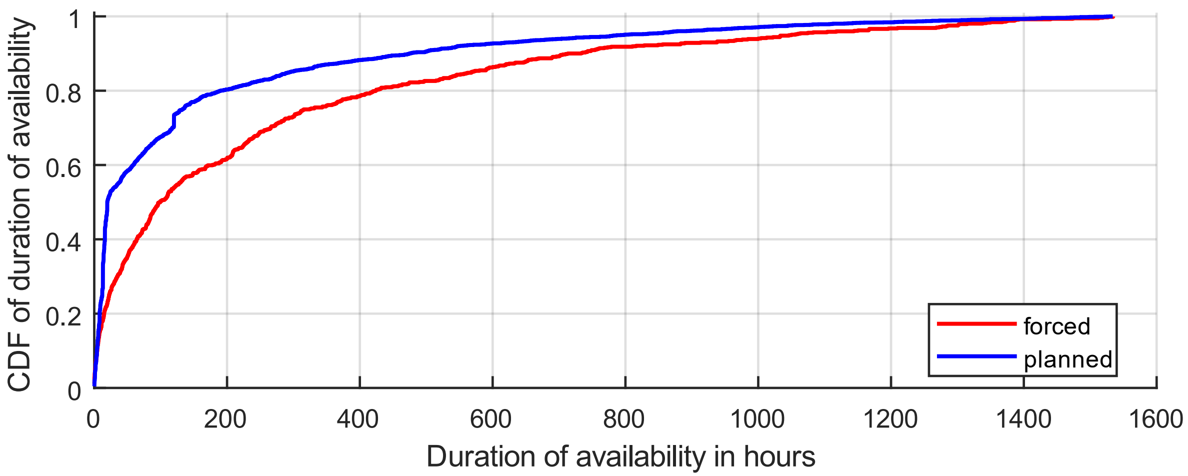
- 13,322 observations of ENTSO-E transparency platform from 2018 to 2021
- Processed for inconsistencies and outliers
- Figure for German fossil gas power plant

Type	Region	Outages per region	Units per region	Outage Rate
Forced	FR	1.041	22	3,9%
	IT	1.622	89	5,6%
	DE	1.180	52	4,3%
	CHAT	230	16	2,9%
	BeNe	1.168	59	3,3%
Planned	FR	743	21	12,4%
	IT	1.648	89	8,0%
	DE	3.561	57	21,0%
	CHAT	175	15	12,2%
	BeNe	2.169	66	11,7%

Table: Key statistics for fossil gas power plants





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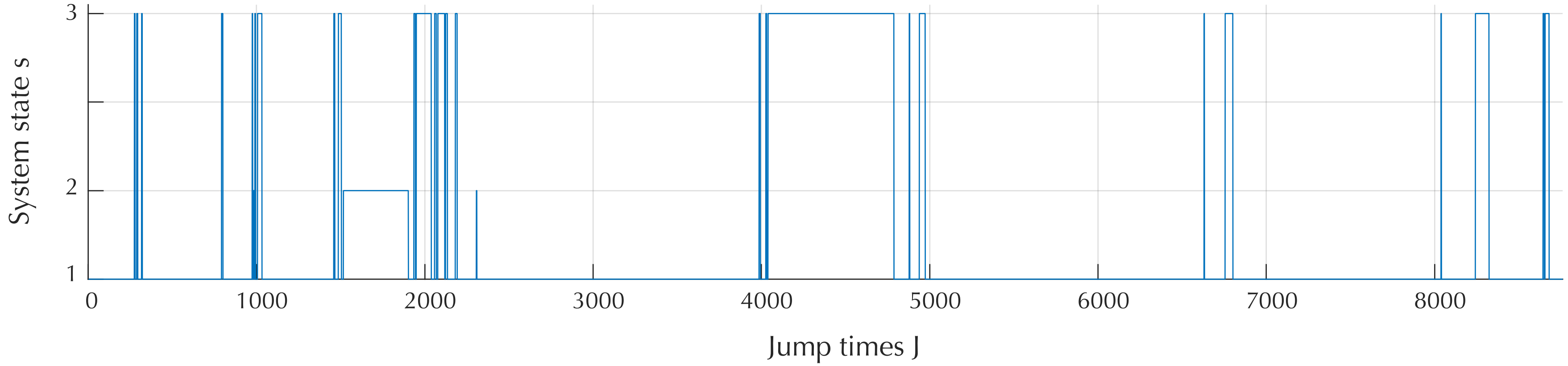
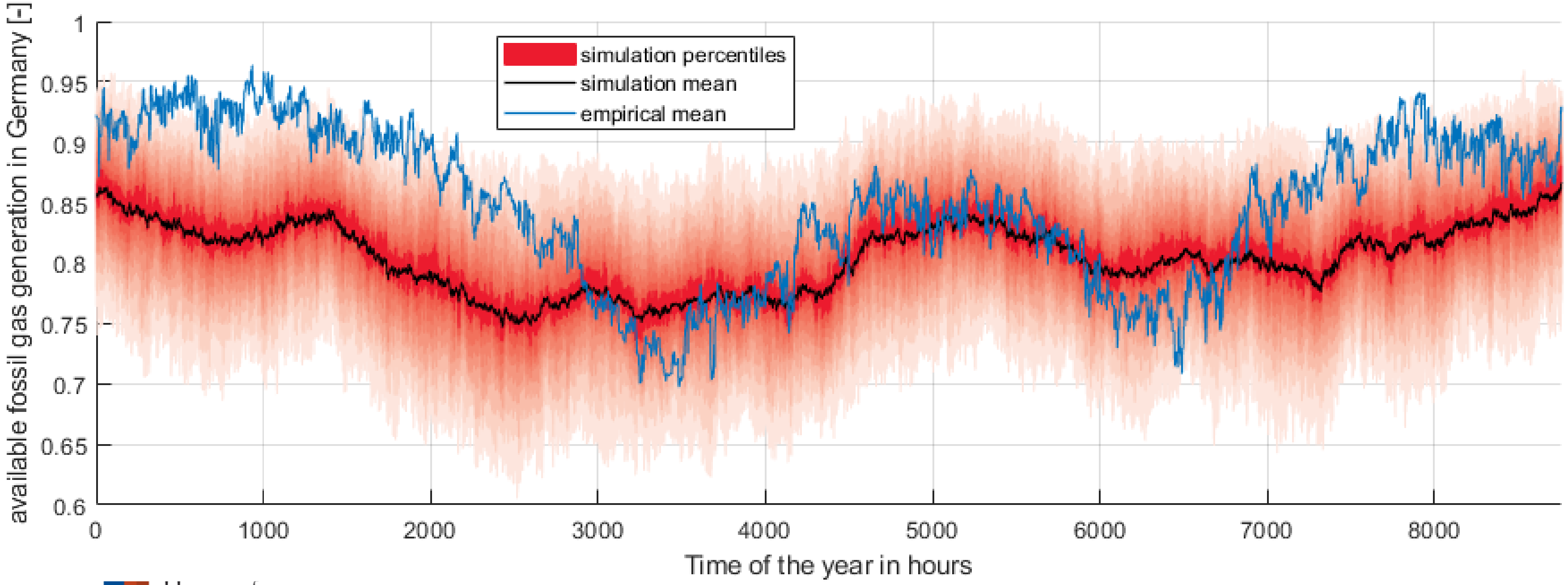
Results – Simulations of generation availability



Simulation of power plant availability $Av_{t,u}$ based on $(\boldsymbol{F}_{t,u}\,,\ \boldsymbol{P}^{m,r})$



Aggregated simulation of generation availability

Conclusion

Empirical analysis of characteristics of power plant outages based on ENTSO-E dataset

- Outages depend on deterministic power plant characteristics such as installed capacity, country of origin, technology group
- Mixture of long but rare high-impact outages and short but frequent low-impact outages
- Impact of partial outages neglectable based on outage intensity
- Planned unavailability with clear seasonal effects

Simulations of power plant availability using semi-Markov model

- Non-homogeneous parametrization to model seasonal effects
- Unit-wise trajectories of availability reflecting power plant characteristics

Thank you for your attention!

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References

- Barbu, V. S., & Limnios, N. (2009). *Semi-Markov chains and hidden semi-Markov models toward applications: their use in reliability and DNA analysis* (Vol. 191). Springer Science & Business Media
- Billinton, Roy; Li, Yifeng (2007): Incorporating multi-state unit models in composite system adequacy assessment. In: *Euro. Trans. Electr. Power 17 (4)*, S. 375-386. DOI: 10.1002/etep.154.
- Bucksteeg, M. (2019). Modelling the impact of geographical diversification of wind turbines on the required firm capacity in Germany. *Applied Energy*, *235*, 1476-1491.
- Gils, H. C., Bothor, S., Genoese, M., & Cao, K. K. (2018). Future security of power supply in Germany—The role of stochastic power plant outages and intermittent generation. *International Journal of Energy Research*, *42*(5), 1894-1913.
- Guerrero-Mestre, V., Poncela, M., Fulli, G., & Contreras, J. (2020). A probabilistic analysis of power generation adequacy towards a climate-neutral Europe. *Energy Reports*, *6*, 3316-3333.
- Nolting, L., Spiegel, T., Reich, M., Adam, M., & Praktiknjo, A. (2020). Can energy system modeling benefit from artificial neural networks? Application of two-stage metamodels to reduce computation of security of supply assessments. *Computers & Industrial Engineering*, *142*, 106334.
- Pievatolo, A.; Tironi, E.; Valade, I. (2004): Semi-Markov Processes for Power System Reliability Assessment With Application to Uninterruptible Power Supply. In: *IEEE Trans. Power Syst*. 19 (3), S. 1326–1333. DOI: 10.1109/TPWRS.2004.826756.
- van Casteren, J.F.L.; Bollen, M.H.J.; Schmieg, M. E. (2000): Reliability assessment in electrical power systems: the Weibull-Markov stochastic model. In: *IEEE Trans. on Ind. Applicat*. 36 (3), S. 911–915. DOI: 10.1109/28.845070.