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Stochastic Modeling of Energy System Uncertainty

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Project workshop (VeSiMa)

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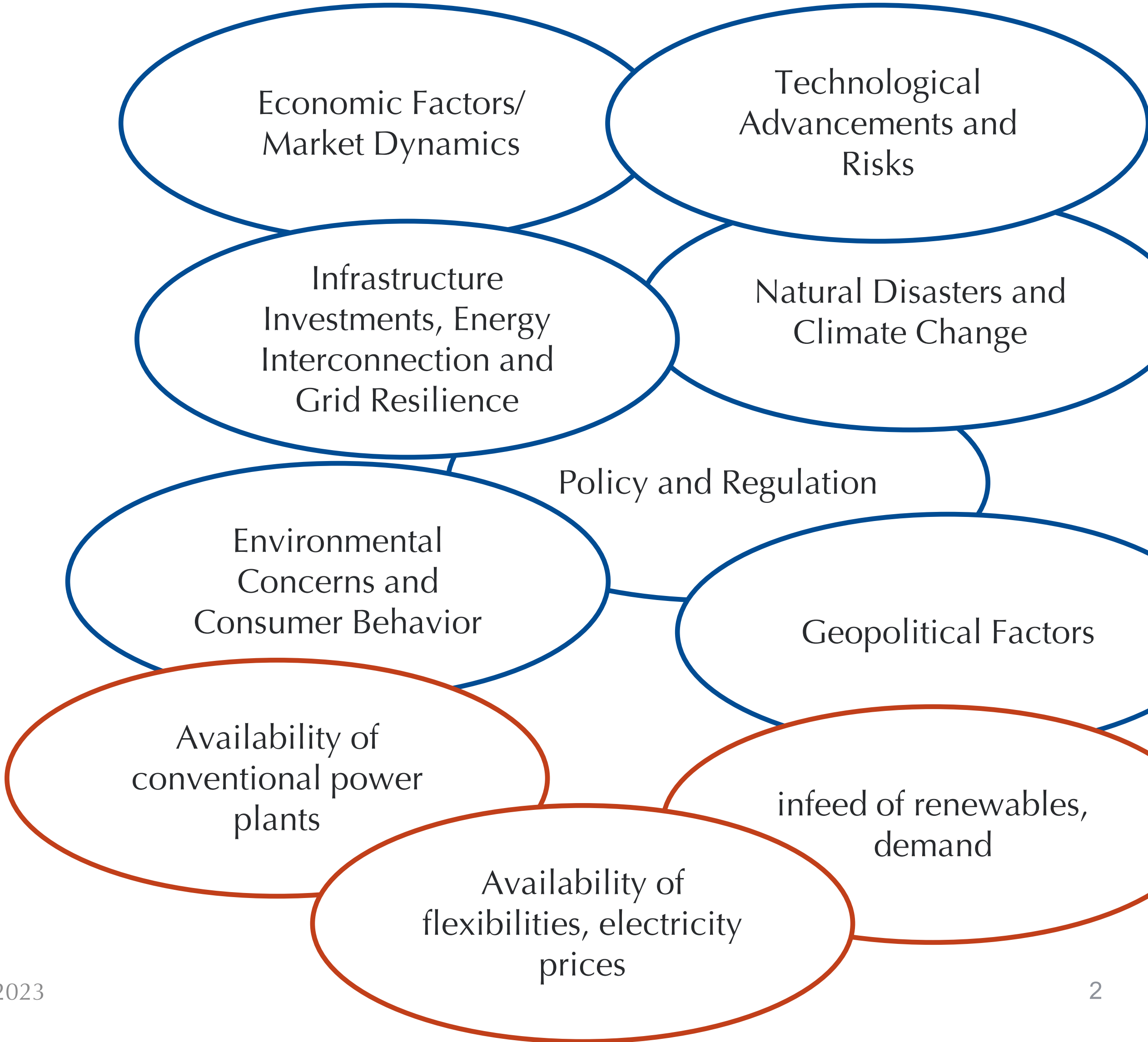
Energy System Uncertainty

- Multiple sources of uncertainty in the future
- Daily challenge of dealing with uncertainties (in private, at work, …)

- Relevance of facing uncertainties in energy system
  - long-term (strategic) planning
  - operational decision-making
  - risk management
  - …
- Differentiation of uncertainty factors:
  - Longer-term uncertainties (see right)
  - Operational uncertainties (see right)

➢ **Monitoring and management of uncertainties**



Basic approaches for dealing with uncertainties

- **Scenarios**: mainly used to cope with long-term uncertainties
  - built on explicit assumptions
  - "what if" – business-as-usual, green, optimistic, pessimistic, …
  - are used in typical electricity system (optimization) models

- **Weather years**: mainly used to cope with operational uncertainties
  - use of previously observed weather conditions from past years
  - "what if" – historical weather conditions occur again (with changed generation mix, demand pattern, …)

- **Stochastic modeling**: mainly used to cope operational uncertainties
  - empirical observations of weather and system characteristics from past years
  - "learn from the past, but also anticipate new things" – occurrence of unprecedented (possibly rare) situations

Overview stochastic modelling

- Objective:
  - Building on empirical observations
  - Extracting key characteristics driving daily operations
  - Simulating future possible situations, capturing the entire spectrum of possible values

Implemented modelling approach considers

- Structural (fundamental) dependencies
- Time dependencies
- Additional dependencies
  - Cross-spatial
  - Cross-technological

Project context:

A

Stochastic characterization with quantile regression and joint normal transformation

Spatio-temporally dependent **Monte Carlo simulation** and joint re-transformation

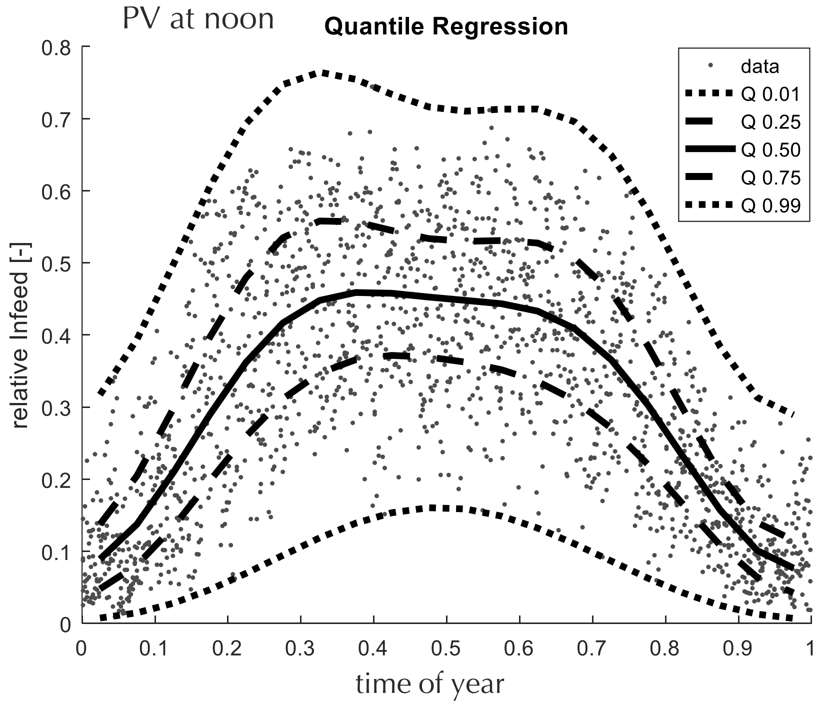
B

Parameterization of **semi-Markov model** and unit-wise simulation

Least-squares Monte Carlo model to determine storage operation

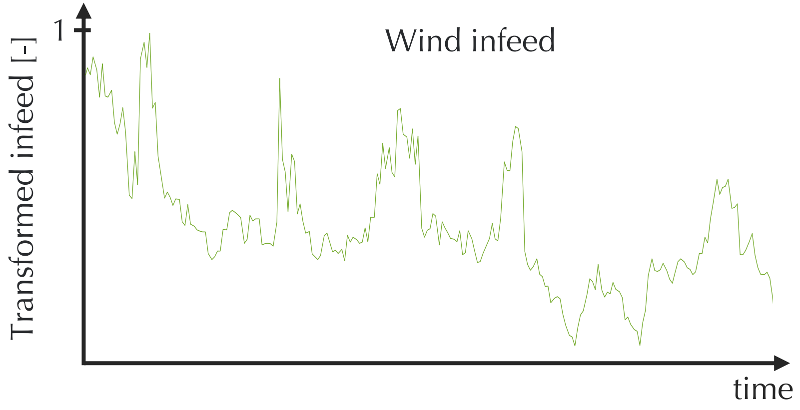
Modeling structural (fundamental) dependencies

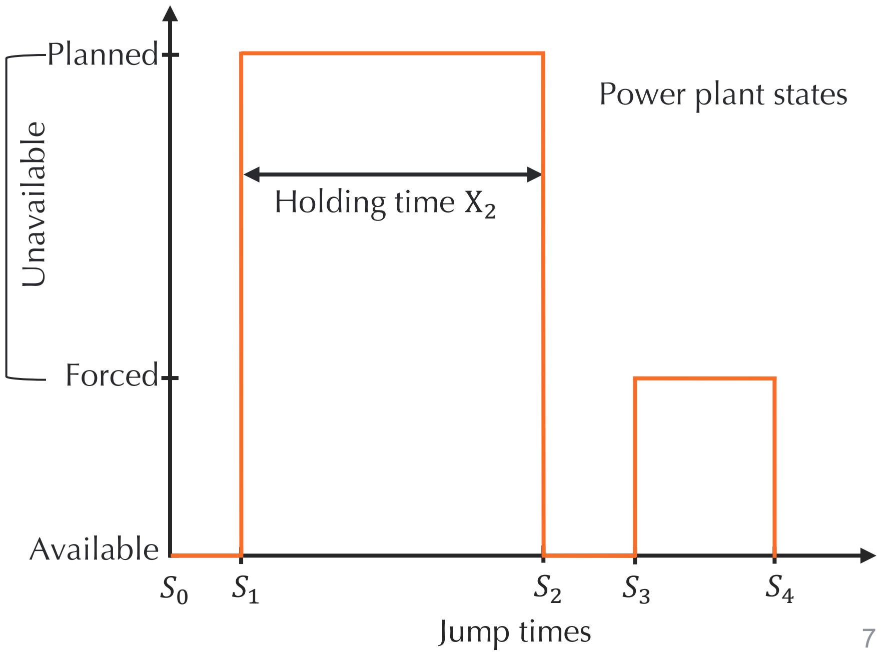
- Objective:
  - Describe and capture fundamental dependencies and full range of possible values (not just the expected or most likely value)
- Modeling approach: **Quantile regression**
  - allows to estimate individual quantiles depending on explanatory variables (time of year, time of day, …)
  - Quantiles describe threshold values below which the values are expected to lie with a certain probability
- Usage of the approach:
  - Description of structural dependencies in time series
  - Elimination of these dependencies to allow further investigations
  - Simulations including theses structural aspects



Modeling time dependencies

- Objective:
  - Describe and capture time dependency
- Modeling approaches:
  - **Auto-regressive models**: describe current value as a function of one or several past values
  - **Semi-Markov chains**: describe transitions between different states occuring at irregular and unpredictable time intervals
- Usage of the approaches:
  - Auto-regressive models: simulating renewable infeed
  - Semi-Markov-chain: simulating occurrence and duration of planned and unplanned outages of technologies

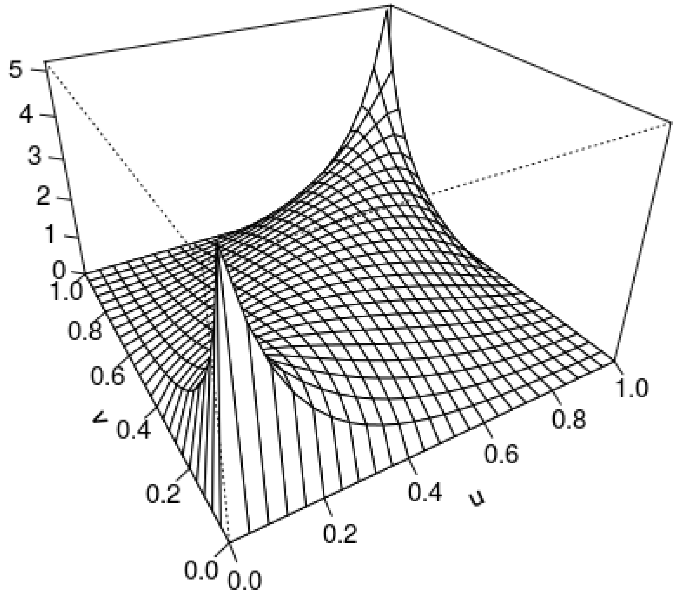




Modeling additional dependencies

- Objective:
  - Describe and capture additional dependencies like cross-spatial and cross-technological
- Modeling approach: **Copula**
  - allow to capture dependencies between different time-series
  - Coefficients indicate the strength and direction of a relationship, e.g. correlation matrix in Gaussian Copula values from -1 (perfect negative) to 0 (no relationship) to 1 (perfect positive)
- Usage of the approach:
  - Capturing of additional dependencies
  - Consideration these dependencies when simulating multiple consistent time-series

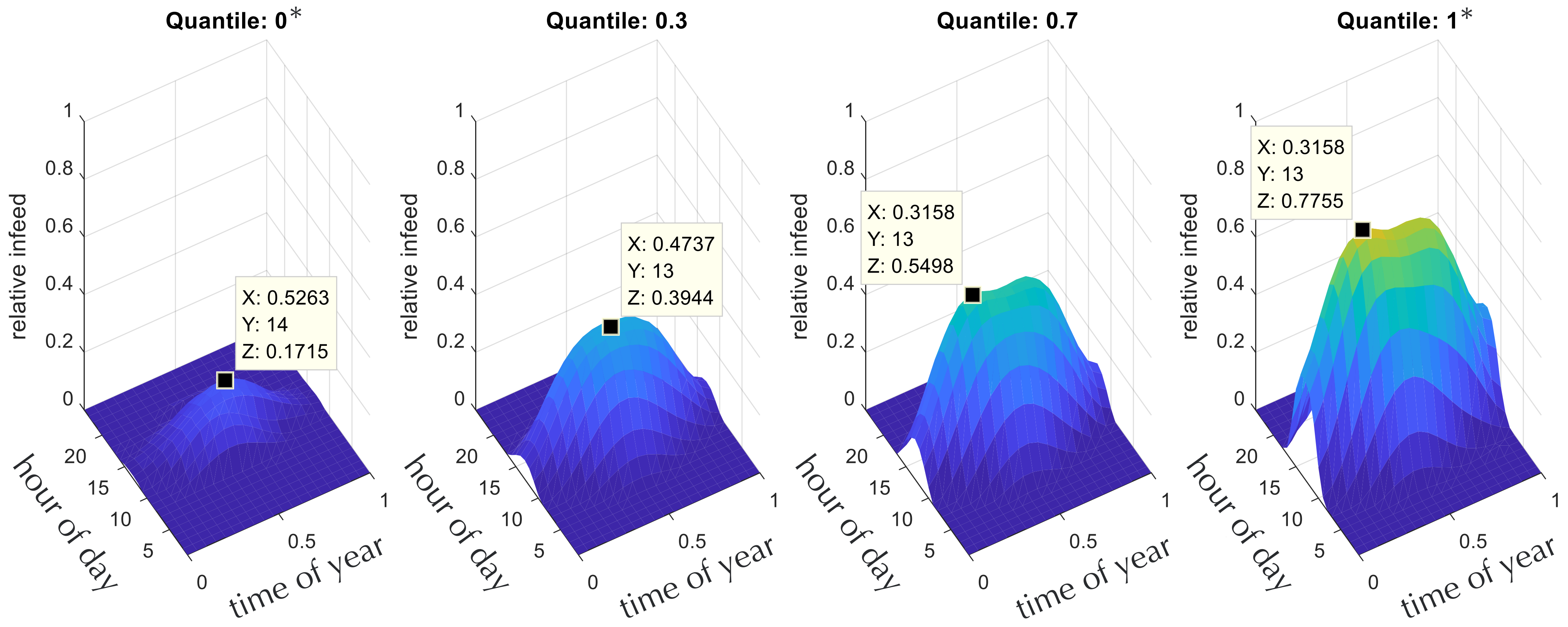
Gaussian Copula



Exemplary application

Quantile Regression: Photovoltaic infeed in Germany

Source: ENTSO-E Transparency Platform



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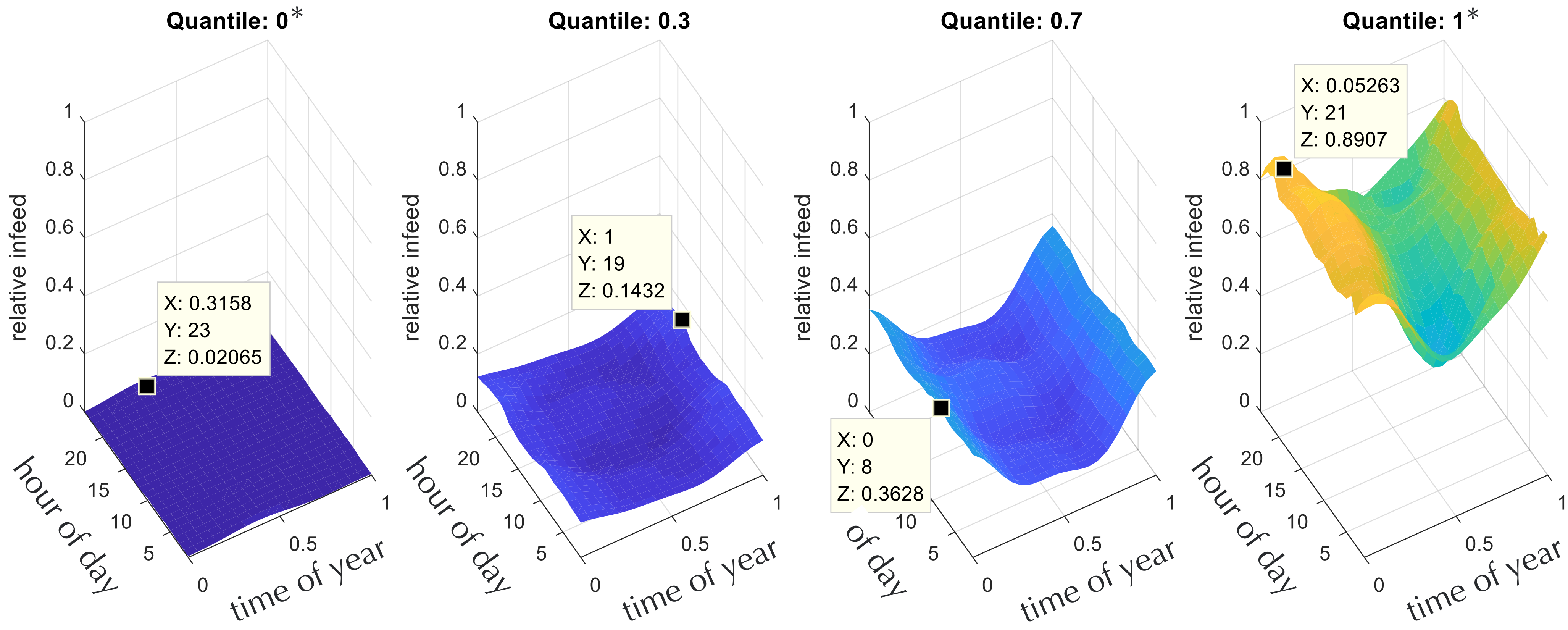
Quantile Regression: Wind infeed in Germany

Source: ENTSO-E Transparency Platform



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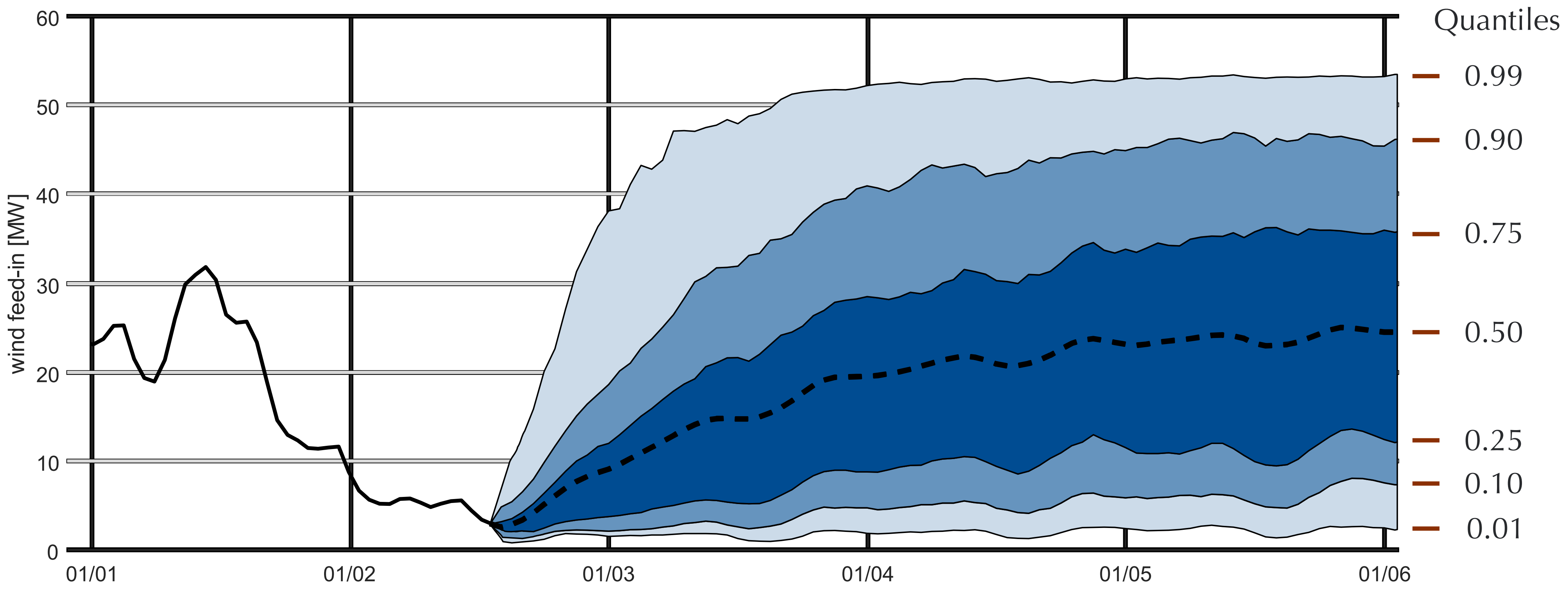
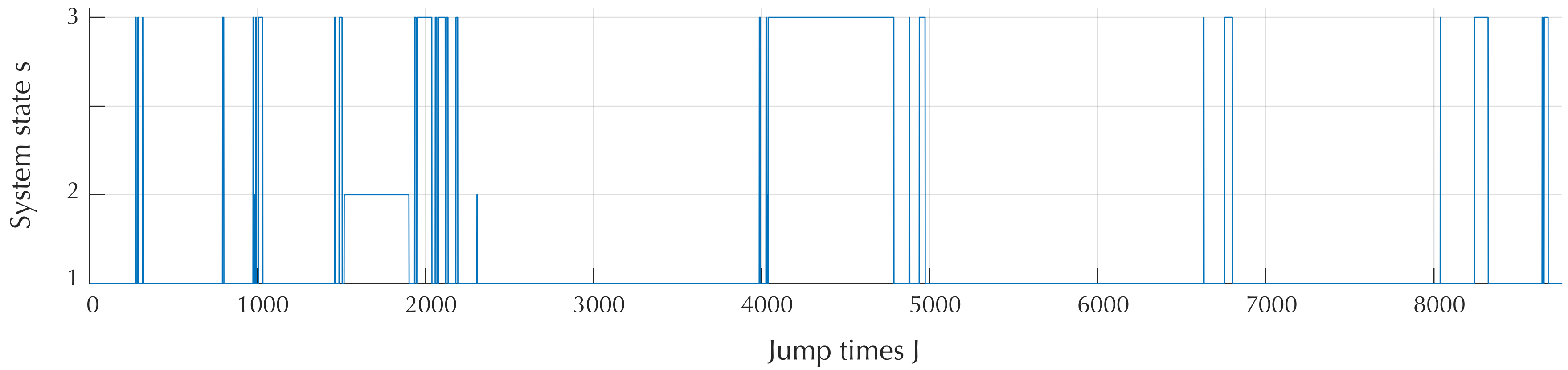
Auto-regressive models: Wind Onshore

Source: ENTSO-E Transparency Platform

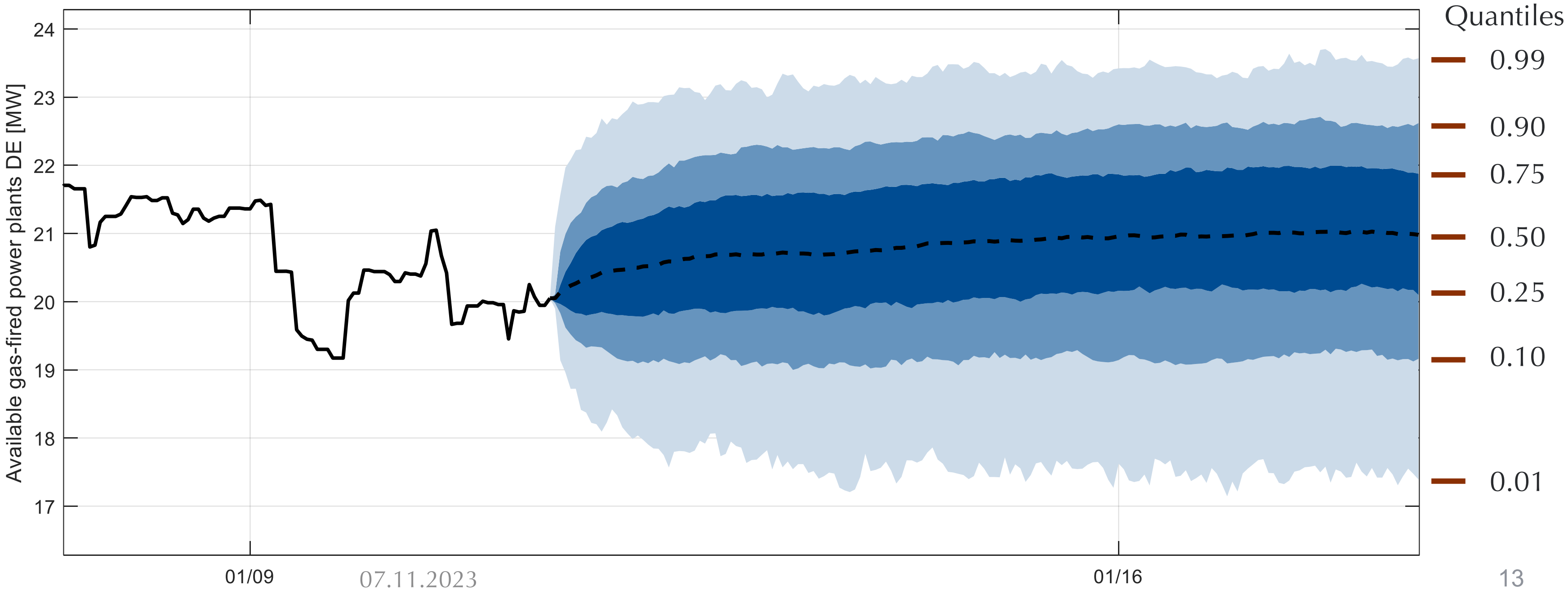


Semi-Markov-chain: Gas Units DE

- Single simulation



- Aggregated to availability of gas-fired power plants (DE)



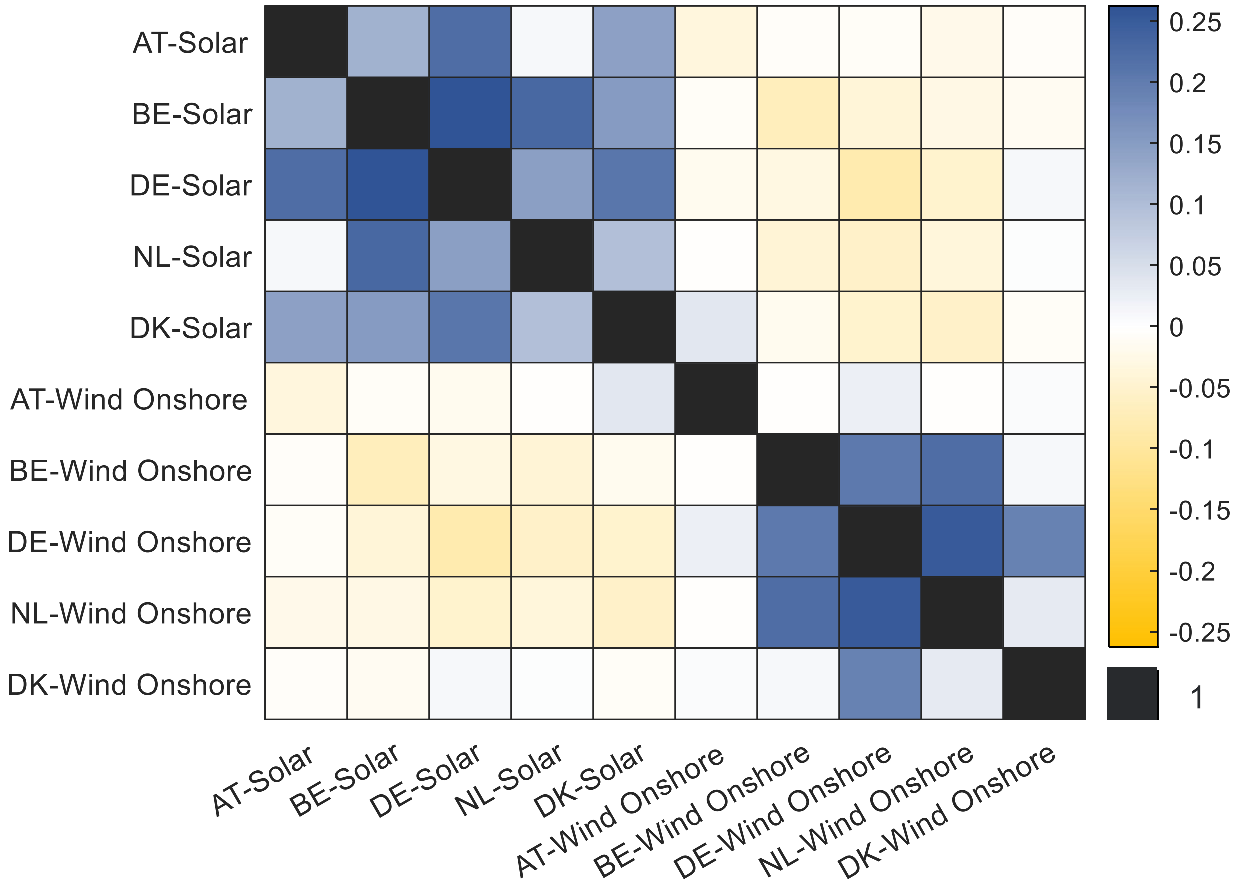
Source: ENTSO-E Transparency Platform

Copula: Photovoltaic and Wind Onshore infeed

Source: ENTSO-E Transparency Platform

Key-findings:

- Positive cross-spatial relationship between neighboring countries for both solar and wind-onshore infeed
- Slight negative cross-technology relationship between solar and wind-onshore infeed



Usage of stochastic modeling (selection)

- Simulating national renewable infeed, demand and availability of conventional power plants (considering cross-country correlations)
  - Adequacy Assessments (VeSiMa context)
  - Price Simulation
  - Valuation of renewables (e.g. PPA context)
  - Valuation of flexibilities (e.g. battery systems)

- Simulation of multiple individual photovoltaic infeed time series while maintaining consistency with national infeed and associated prices.
  - Analyze grid states to optimize grid operation as well as expansion respectively reinforcement plans
  - Valuation of local flexibilities (e.g. battery system in the industry, combined with pv or private household)

Added value

- Adequacy Assessments (VeSiMa context)
  - High relevance to capture especially the rare situations with potential supply problems
  - Fast modelling approach allows to simulate several thousand up to millions of possible variants of a selected years

- Simulating renewables infeed, availabilities of renewables and prices
  - Stochastic simulation of multiple realizations covering the full-range of expected values
  - Selecting single representative simulated path for application, which only needs one realization

- Valuation of investments in generation technologies and flexibilities
  - Possibility to valuate investments under uncertainty (stochastic approaches like LSMC)

Conclusion

- Proposed stochastic modeling approach allows to analyze and simulate operational uncertainties
- May be easily adapted to new datasets
- Different tools (quantile regression, autoregression, semi-Markov chain, copula) can be customized for various applications, combined and individually

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Questions?

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Interested in a further discussion about the shown modeling approaches and possible fields of application? Feel free to contact us, benjamin.boecker@uni-due.de

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