Introduction

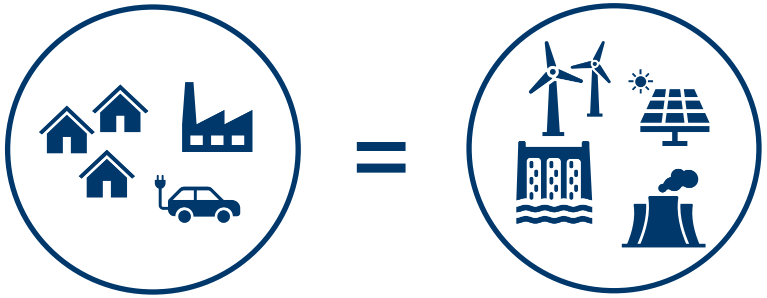
Motivation

- Quantification of power system uncertainties
- Probabilistic assessment of generation adequacy considering temporal and spatial dependencies
- Assessment of consequences of restricted Russian gas supplies and reduced French nuclear generation capacities for generation adequacy

Research questions

- Is the generation adequacy guaranteed in core European countries with restricted Russian gas imports in winter 2022/2023?
- What effect does the availability of thermal generation capacities have on the generation adequacy in the core European countries?

Generation adequacy is the ability of the power system generation to meet the power demand at all points in time (European Commission, 2017).



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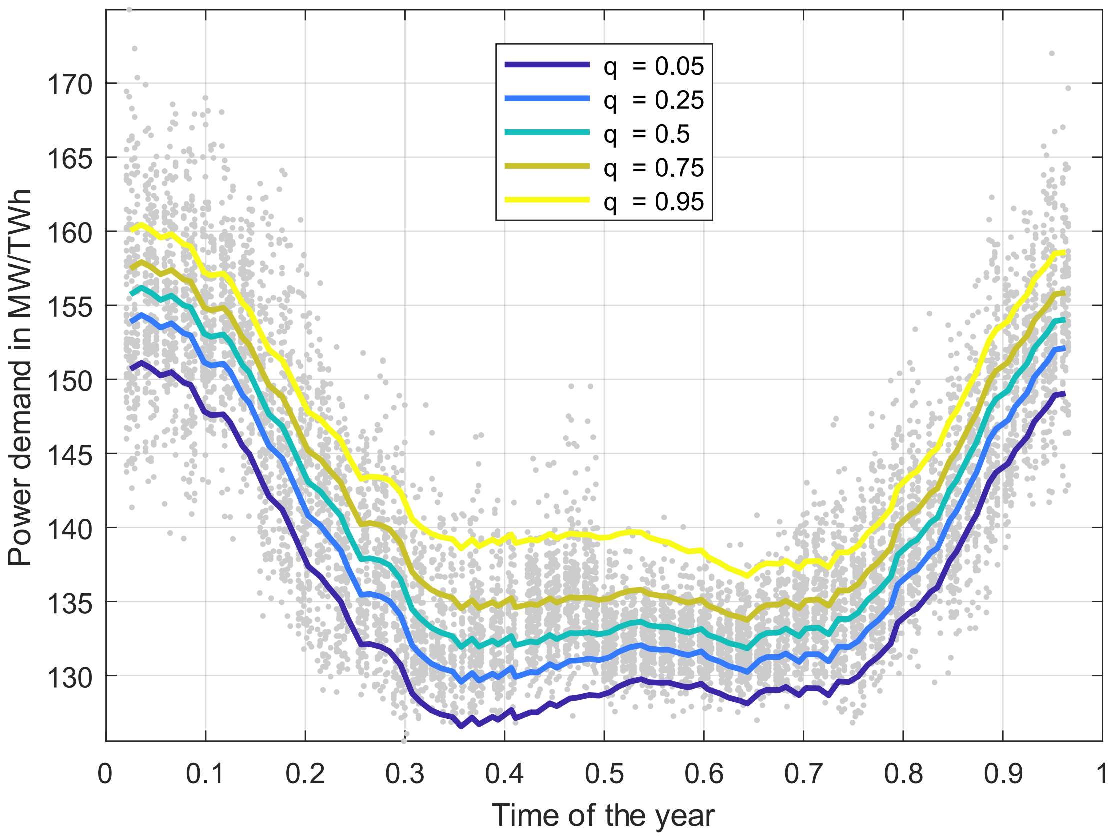
European Commission, 2017. Identification of appropriate generation and system adequacy standards for the internal electricity market: final report

Methodology: Stochastic characterization

Austria: power demand in hour 12



Quantile regressions on functions of t

$$\min \sum_{t \in X_i} d_{q,t}$$

$$d_{q,t} = \begin{cases} q\,|e_{q,t}| & e_q(t) \geq 0 \\ (1-q)\,|e_{q,t}| & e_q(t) < 0 \end{cases}$$

$$e_{q,t} = y_t - f_q(t)$$

q: quantile, $f_q(t)$: parametrized function

$$f_{r,h|q}(t) = \alpha_{0,h,r|q} + \alpha_{1,c,r|q} \cdot cos(2\pi \cdot t) + \alpha_{2,r,h|q} \cdot sin(2\pi \cdot t) + \alpha_{3,r,h|q} \cdot cos(4\pi \cdot t) + \alpha_{4,r,h|q} \cdot sin(4\pi \cdot t)$$

- Estimation of **marginal distribution** as a function of exogenous factors
- **Quantile regression** describes uncertainties by parametric estimations of each quantile with respect to time of the year t, hour of the day h and region r)

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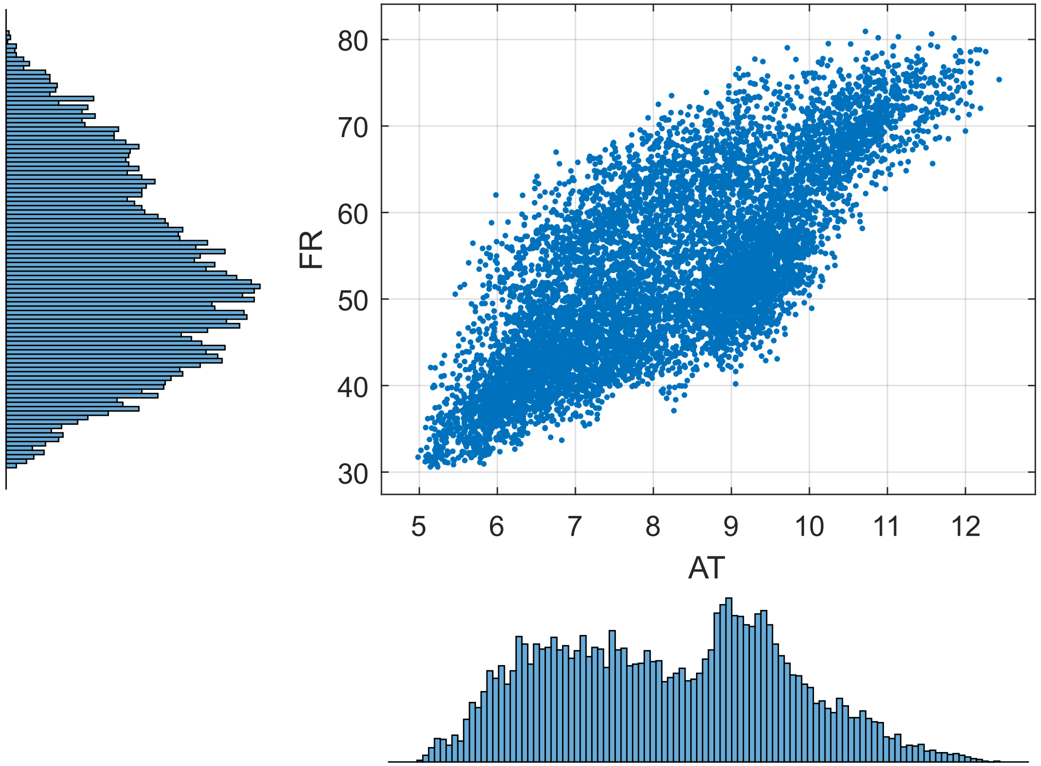
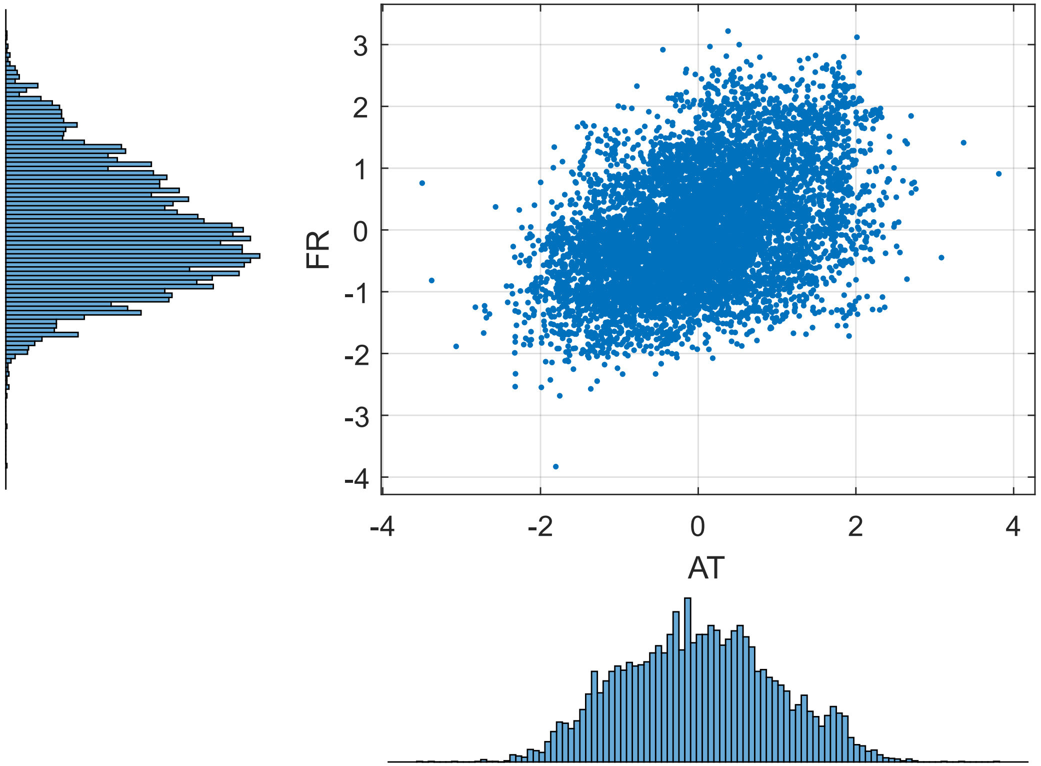
Methodology: Stochastic characterization – Transformation of marginal distributions

Marginals and correlation of power demand in Austria and France



Empirical marginal distributions



Normal marginal distributions

1. Separation of marginal distributions and their joint dependence structure
2. Parameterization of vector autoregressive model for simulation of spatial and temporal dependent uncertainty factors

Generation adequacy assessment: General approach

Temperature-dependent power demand

Onshore & offshore wind infeed

Photovoltaic infeed

Run-of-river infeed

Scenario data of installed RES, thermal and storage capacities, expected load

Historical time series of RES infeed, demand and temperature

I.

Stochastic characterization with quantile regression and joint normal transformation

spatio-temporal dependent **Monte Carlo simulation** and joint re-transformation

Residual load

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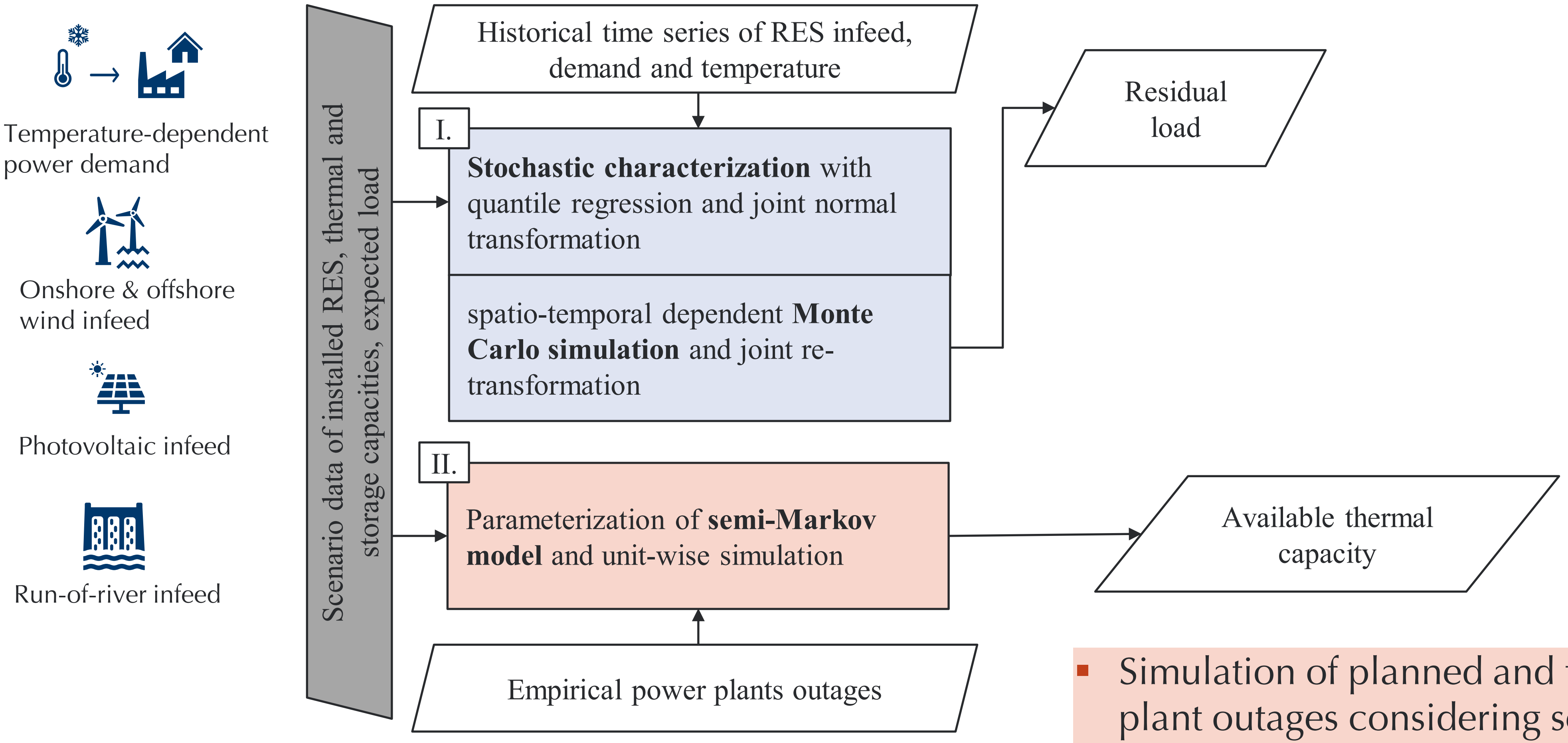
Generation adequacy assessment: General approach



- Simulation of planned and forced power plant outages considering seasonal effects and power plant characteristics
- Consideration of CHP restrictions

Generation adequacy assessment: General approach

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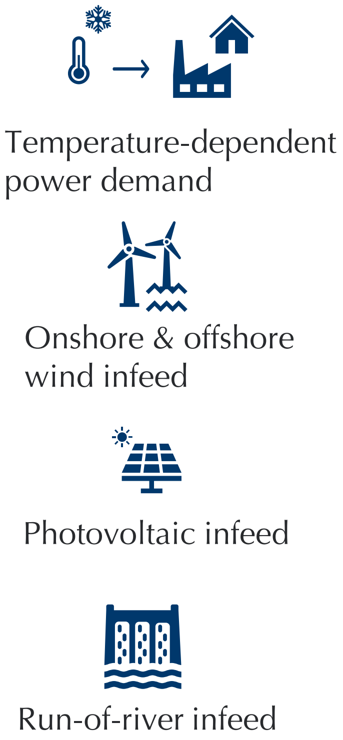
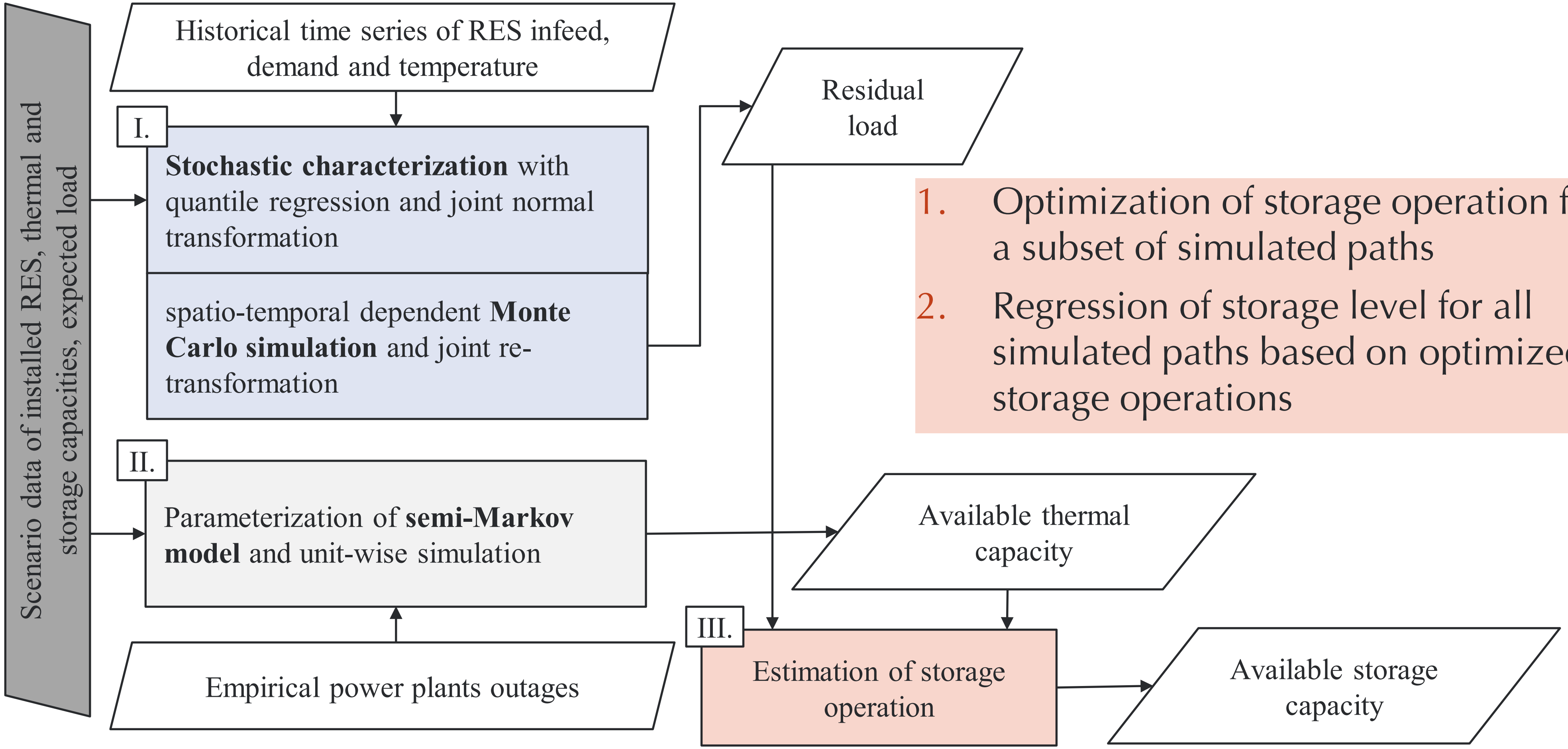
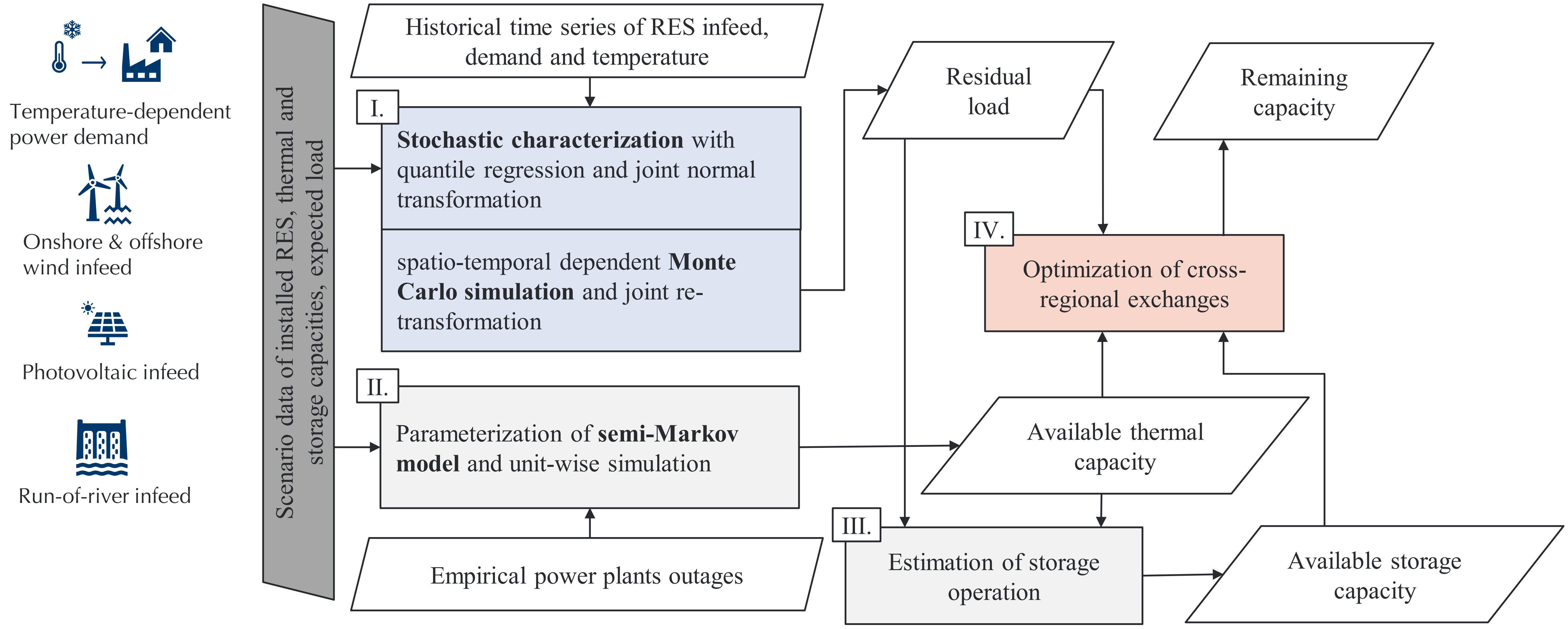




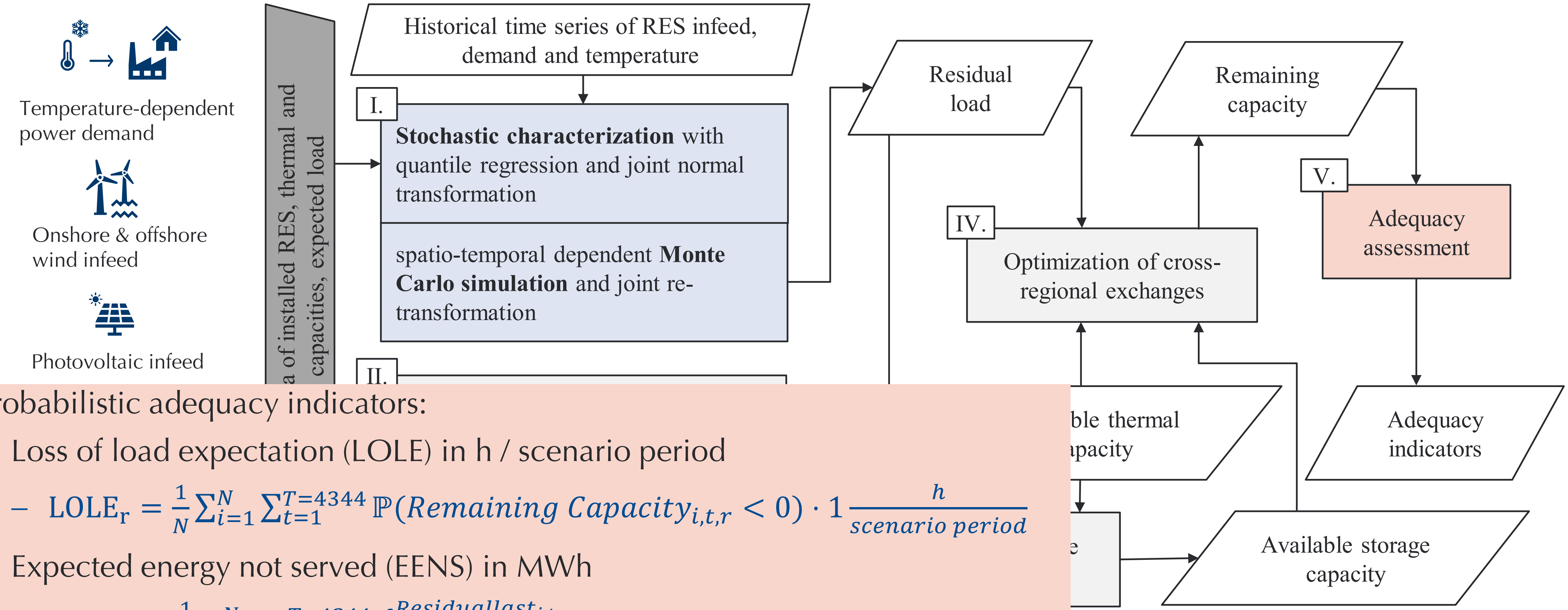
1. Optimization of storage operation for a subset of simulated paths
2. Regression of storage level for all simulated paths based on optimized storage operations

Generation adequacy assessment: General approach



- For all simulated paths with negative remaining capacity in any region: Optimization of cross-regional exchanges via net-transfer capacities

Generation adequacy assessment: General approach



Probabilistic adequacy indicators:

- Loss of load expectation (LOLE) in h / scenario period
  - $\mathrm{LOLE_r} = \frac{1}{N}\sum_{i=1}^{N}\sum_{t=1}^{T=4344}\mathbb{P}(Remaining\ Capacity_{i,t,r} < 0)\cdot 1\,\frac{h}{scenario\ period}$
- Expected energy not served (EENS) in MWh
  - $EENS_r = \frac{1}{N}\sum_{i=1}^{N}\sum_{t=1}^{T=4344}\int_{0}^{Residuallast_{i,t,r}} Remaining\ Capacity_{i,t,r}$

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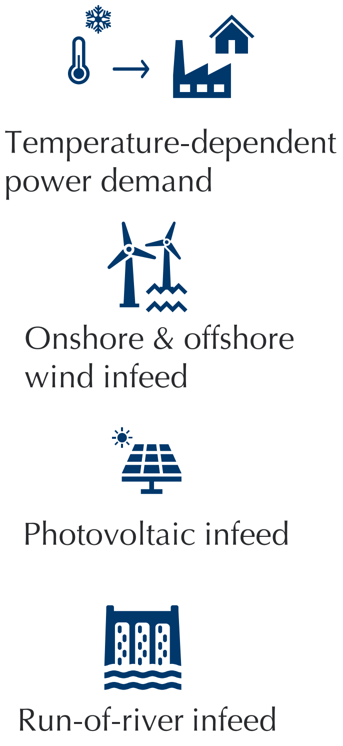
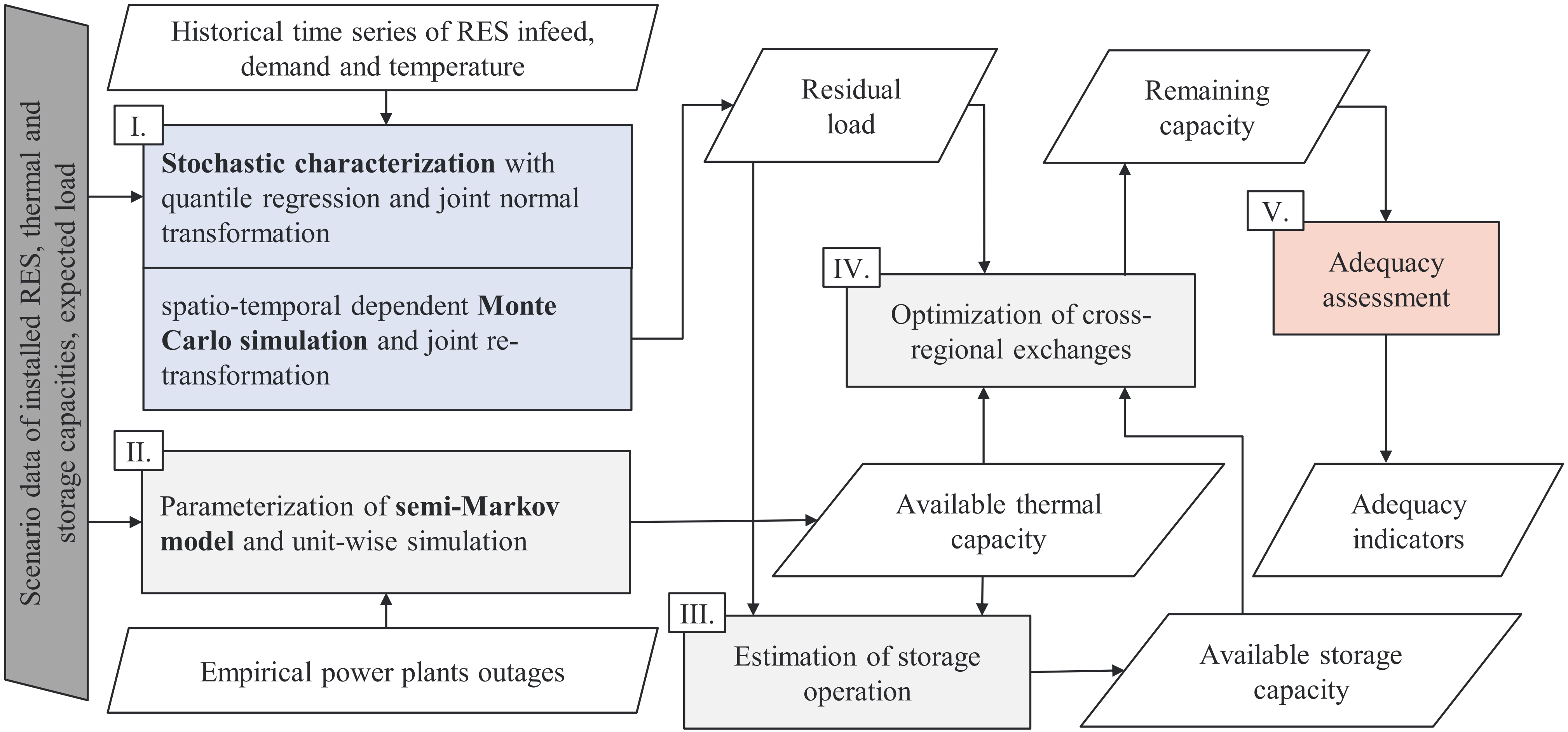
Generation adequacy assessment: General approach





Case study: Scope & Scenarios

- Scenario period: 01.10.2022 – 31.03.2023
- Scenarios with 1000 simulations each
  - **Reference (S1):** Installed generation capacities, power demand and net transfer capacities based on 2022 according to ENTSO-E Transparency Platform
  - **Gas shortage (S2):** Maximum of 70 % gas power plants available in all regions
  - **Nuclear outage (S3):** French and German nuclear power plants available according to observations / predictions
  - **Heating substitution (S4):** Increased temperature sensitivity and subsequently power demand in Germany
  - **Combined (S5):** S2 & S3 & S4
- Data:
  - Characterization: ENTSO-E Pan-European Climate Database from ERAA 2021
  - Scenario: ENTSO-E Transparency Platform

Geographical scope: AT, BE, CH, CZ, DE_LU, DK, FR, IT, NL, PL

Case study: Results –Loss of load expectation (LOLE)

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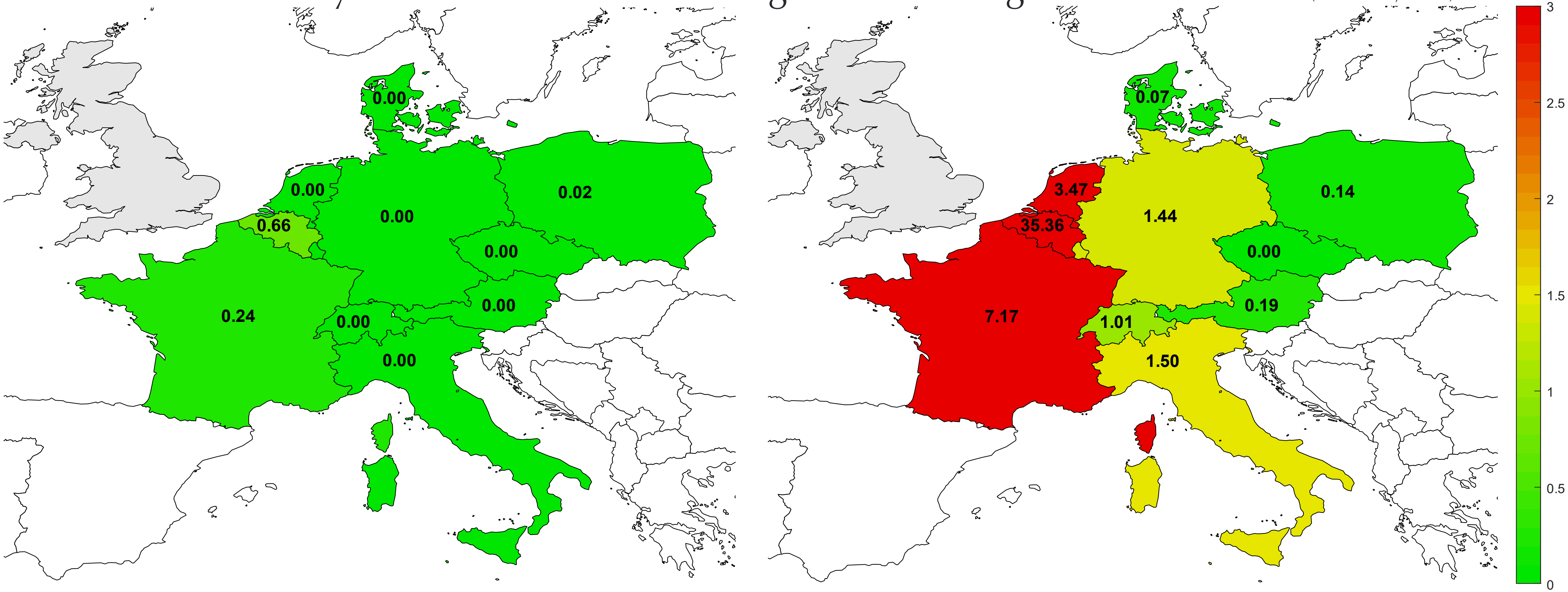
Loss of load expectation (LOLE) in h / scenario period

- National reliability standards of examined regions on average: LOLE = 3 h / a (ENTSO-E, 2022)



Reference scenario (S1) **Combined scenario (S5)**

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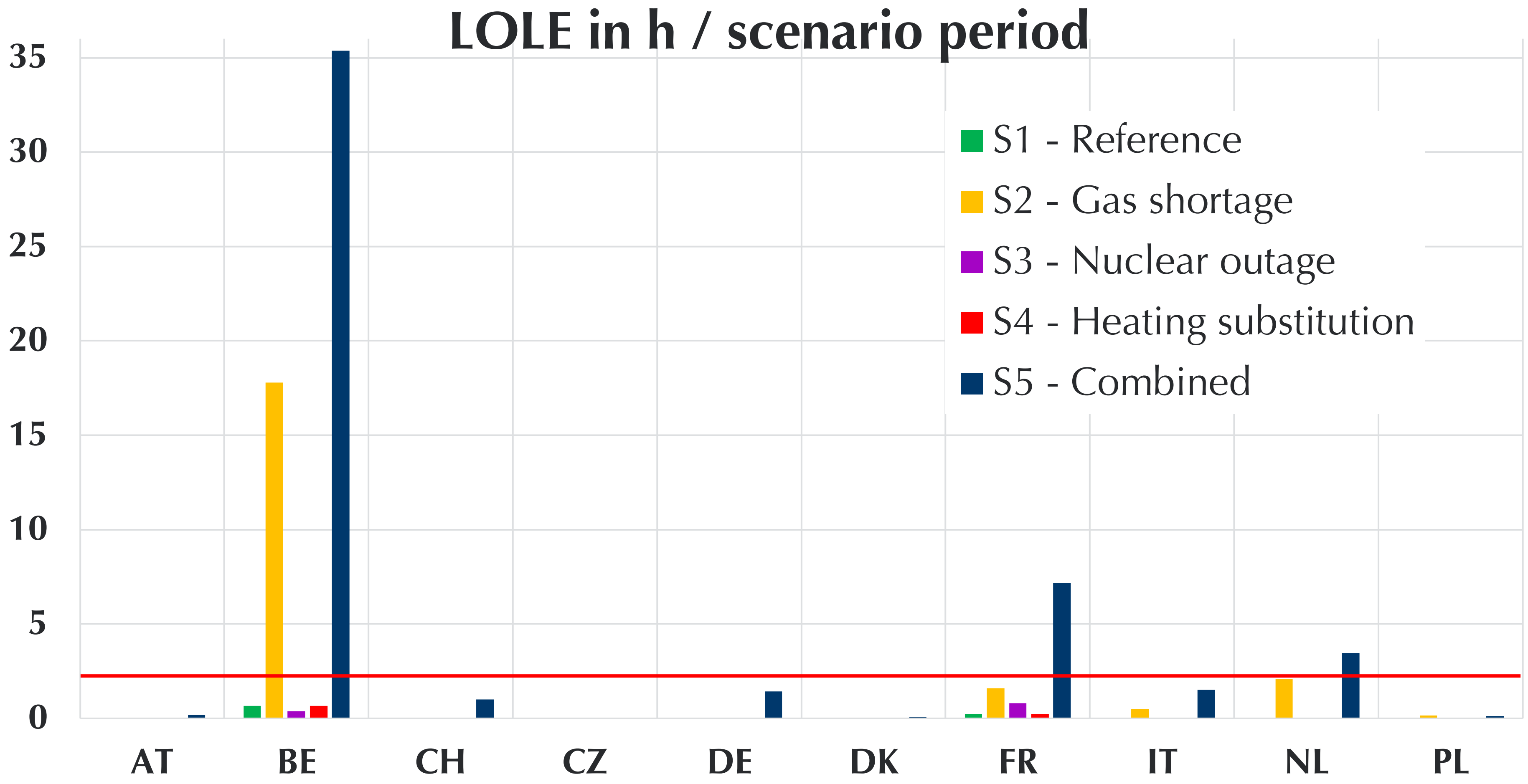
ENTSO-E, 2022. European Resource Adequacy Assessment (ERAA) 2022 – Executive Report: https://www.entsoe.eu/outlooks/eraa/2022/

Case study: Results – S1 – S5: Adequacy indicators



	AT	BE	CH	CZ	DE	DK	FR	IT	NL	PL
S5	0,00	23.266,52	550,39	0,00	3.535,29	0,38	23.077,36	1.528,09	2.343,84	69,09

Expected energy not served (EENS) in MWh in combined scenario (S5)

- S2: Highest individual impact in LOLE
- S1 to S4: Compensating effects of hydro storages and cross-regional exchanges mitigate power deficits in most regions and scenarios
- S5: Combined constraints result in highest LOLE in all regions

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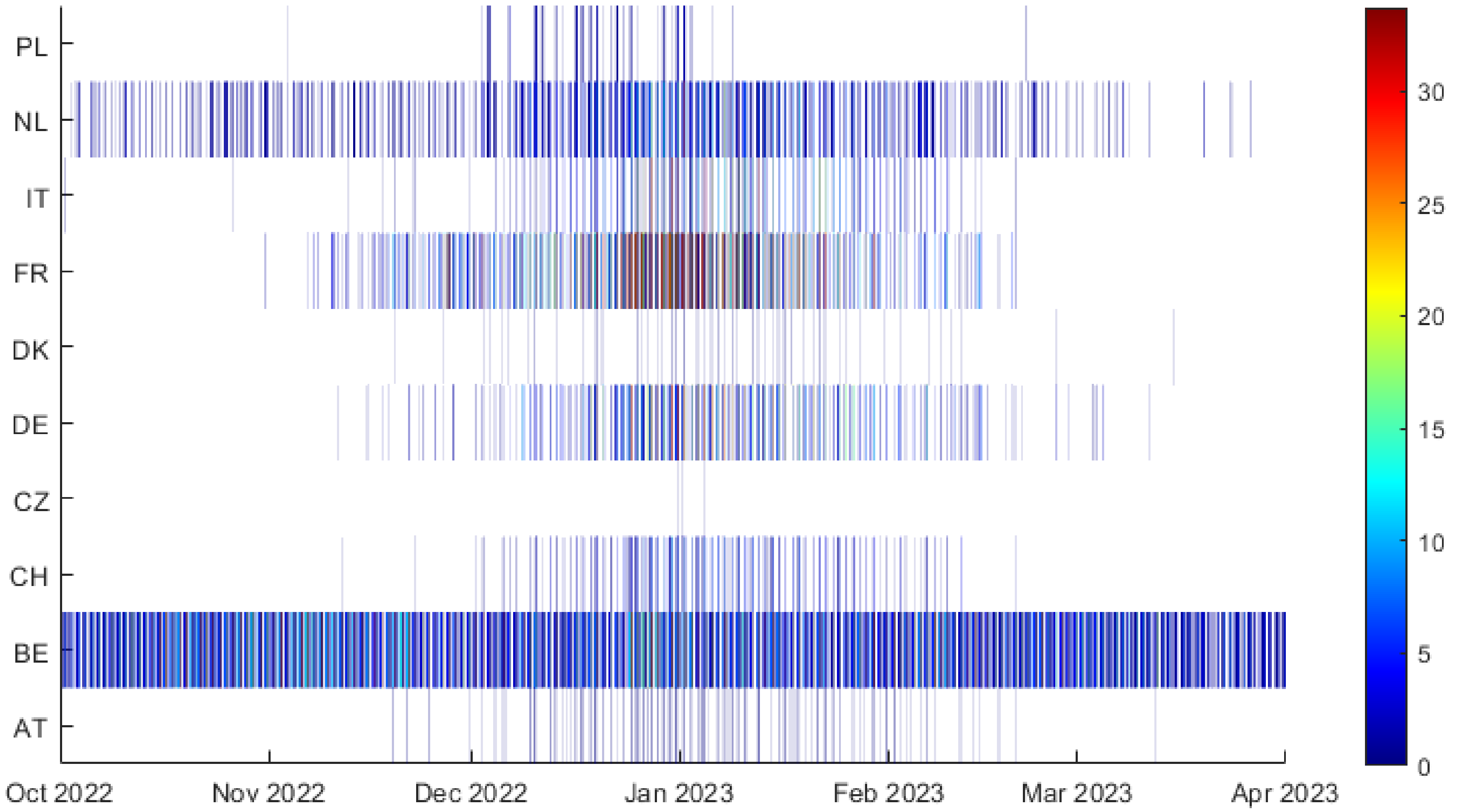
EENS per hour in MW in combined scenario (S5)



- Average energy not served of 1000 simulations per hour
- BE & NL: Systematic lack of generation capacity
- FR: Several hours of higher EENS

Conclusion

Probabilistic assessment of generation adequacy in winter 2022/2023 in core European countries

- Monte Carlo simulation considering probability of occurrence of power system uncertainties plus their spatial and temporal dependencies
- Energy storages and cross-regional exchanges significantly improve level of generation adequacy in all examined regions

- Critical levels of generation adequacy in Belgium, France and the Netherlands, if
  - availability of gas-fired power plants restricted to 70 %
  - French nuclear power plants restricted
  - power demand in Germany increased, due to heating substitution effects
- Additional dispatchable generation capacities necessary to ensure generation adequacy
- Modeling of energy storages critical for generation adequacy assessment

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