The probability of long phases without wind power and their impact on an energy system with high share of renewable energies

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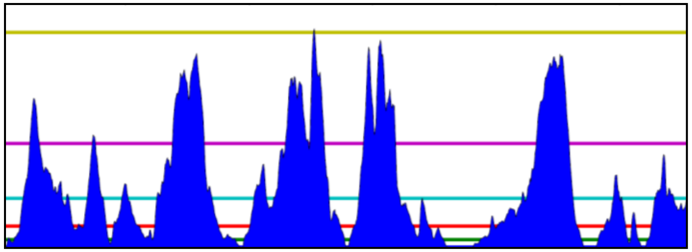

Enerday TU Dresden, 11. April 2014

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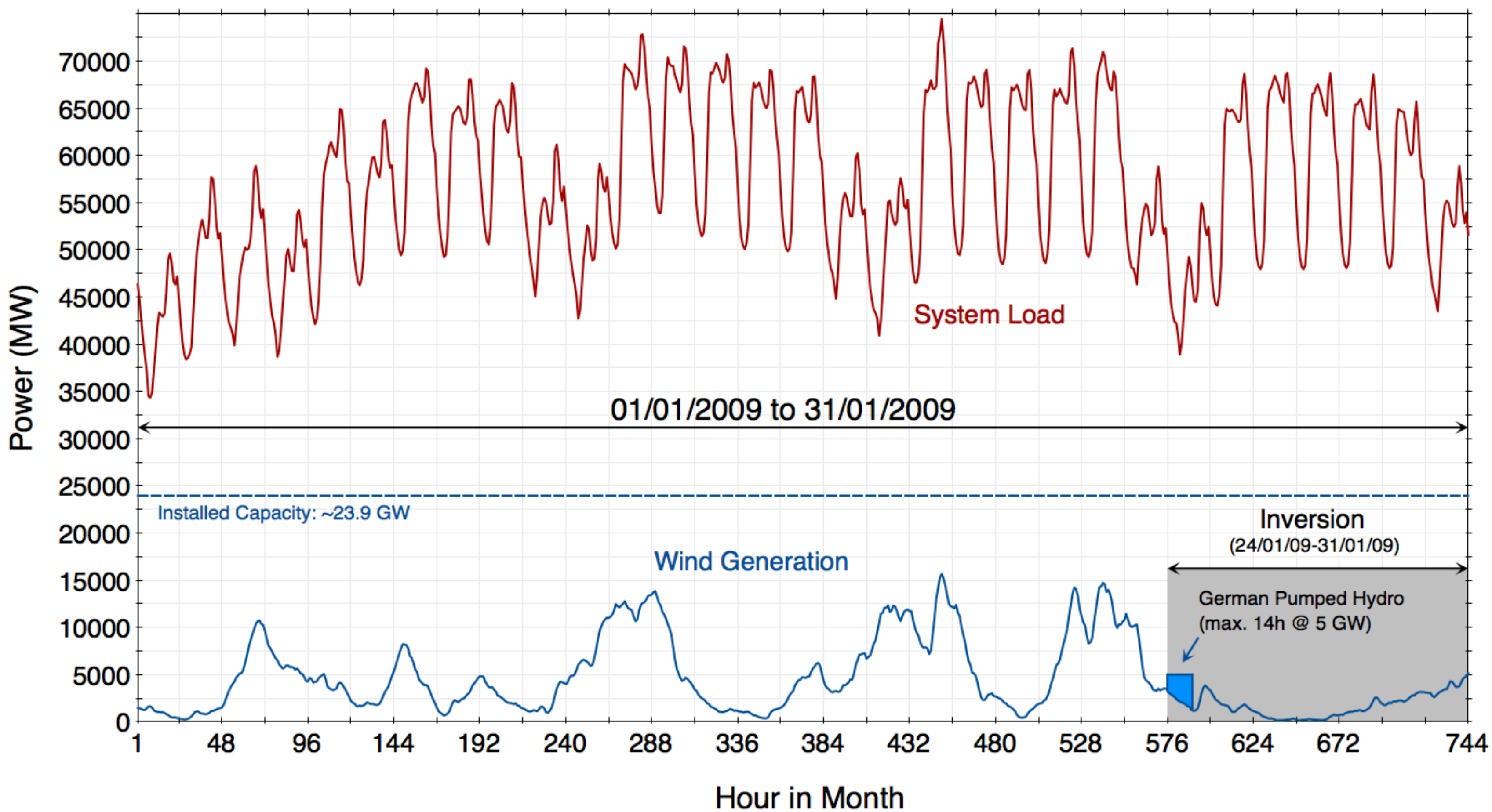
Challenge of future energy system: Long periods of low renewable generation



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Motivation

Comparability of energy system models

- Results of energy system simulation strongly depend on input data e.g. time series for feed-in of renewable energy sources
- Characteristic of feed-in time series often not analysed in detail
- ➢ Analysis and evaluation of the representativeness of time series could improve the comparability of different model results.

Need for flexibility options

- Characteristic of residual load varies for different years with regard to duration, frequency and time-correlation of low and high residual load
- The need for flexibility options like storage technologies, DSM or flexible power plants depends on the characteristic of the residual load time series
- ➢ A more detailed understanding of residual load data is favourable.

➢ **A better understanding of renewable feed-in and residual load times series data is useful for energy system analysis.**

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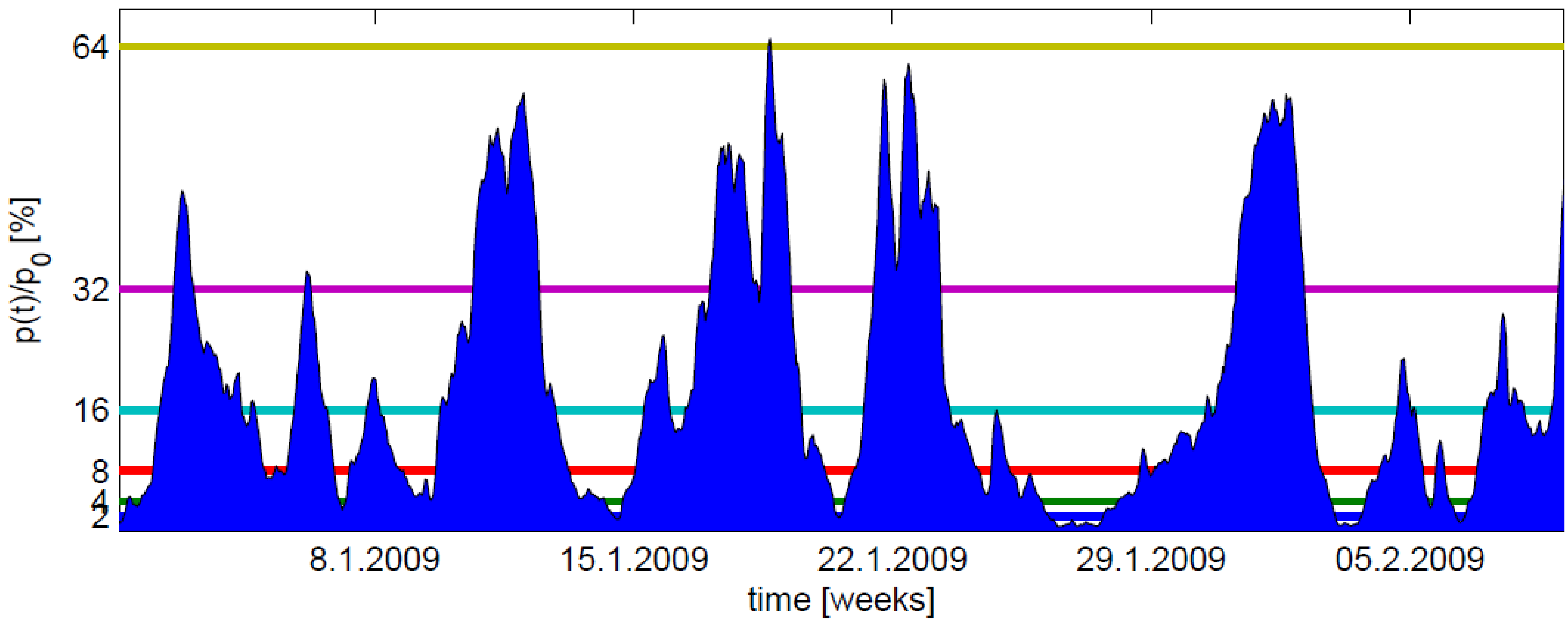
Data: Hourly wind & PV feed-in plus residual load in Germany 2006 – 2012 time series

- feed-in time series of renewable energy sources, available on netztransparenz.de:
  - Wind onshore 2006 – 2012, normalised to installed capacity
  - Photovoltaics 2012, rescaled for 2006 – 2011 by installed capacity
- load data 2006 – 2012 (from entso-e.net); *residual load* = load – Wind – PV



Data sources: total wind power feed-in from www.eeg-kwk.net; installed wind power: Bundesverband Windenergie; Load data: ENTSO-E; PV feed-in: www.eeg-kwk.net; Installed PV power: BDEW

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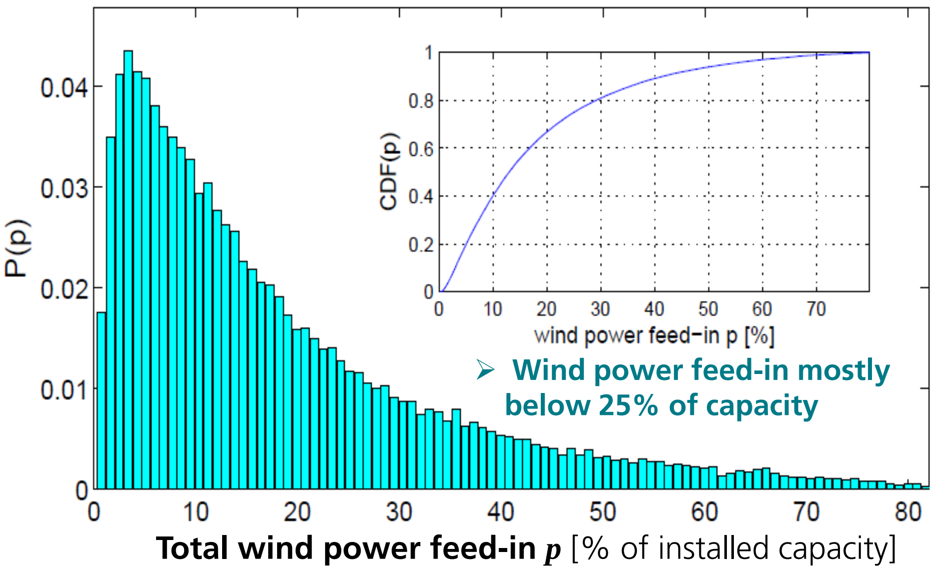
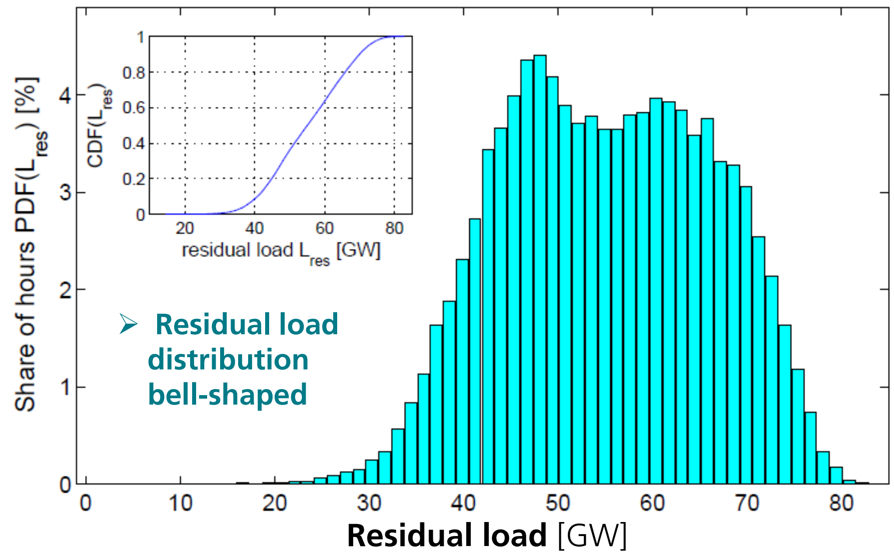
Distribution of normalised wind power feed-in



Distribution of residual loads



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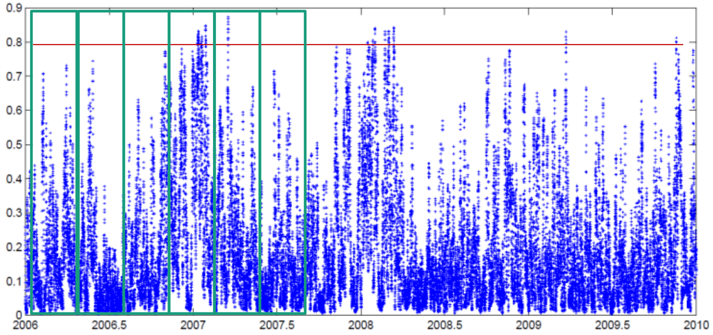
We analyse very long phases of low power or load with extreme value statistics.

- **Extreme value theory** provides statistical tools to quantify the behaviour of a process at extremely large values
- **Extremes** can be defined as
  (1) *maxima within blocks* of data or
  (2) *all values over a threshold*

➢ Choose values above 90%-quantile since phases can be longer than blocks



- The limiting distribution function (CDF) for values x above a threshold u is known

$$\Pr\{x = X - u | X > u\} \xrightarrow{u \to \infty} H_u(x) = 1 - \left(1 + \frac{\xi x}{\tilde{\sigma}}\right)^{-1/\xi} \quad \tilde{\sigma} = \sigma + \xi(u - \mu)$$

- Known as ***Generalised Pareto Distribution*** and similar to central limit theorem: PDF of the mean of many iid random variables always approaches a Gaussian
- **Regression** of parameters usually via **maximum likelihood estimates**
- Numerical parameter values not interesting, but the frequency of maximum values in the future: so-called **return level** (the level that is expected to be exceeded once in N years).

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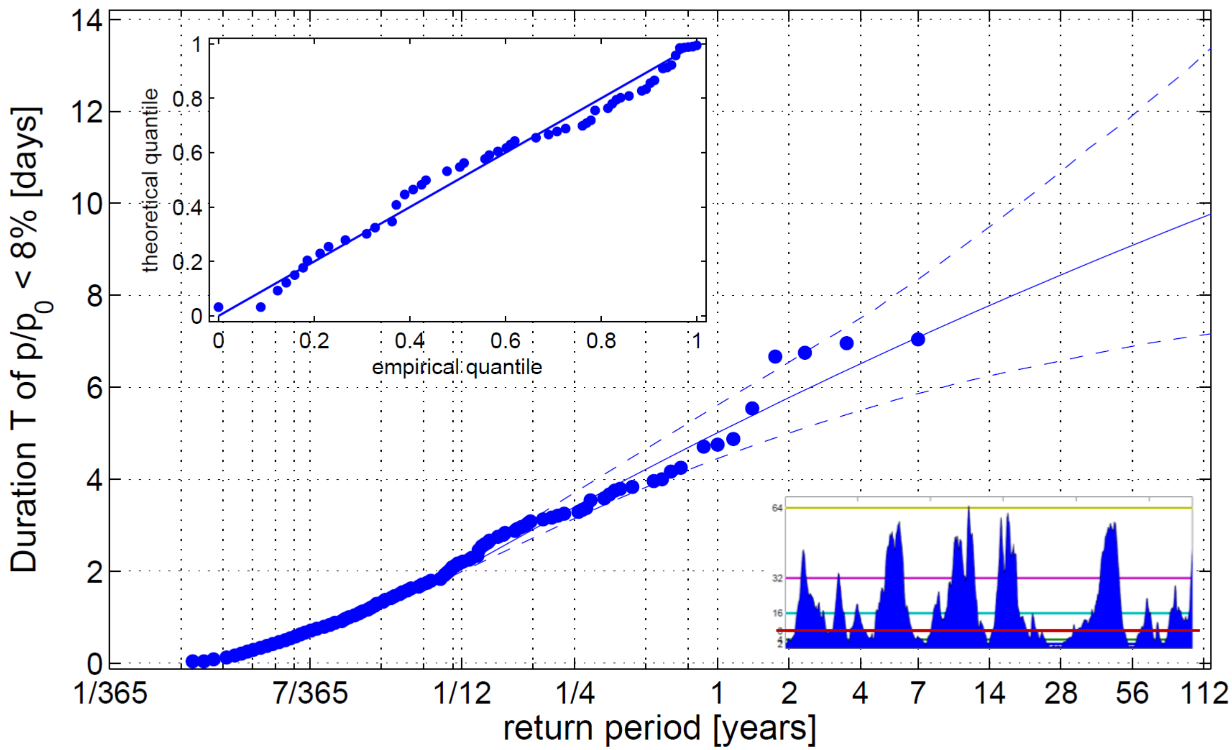
How long are phases of low wind power feed-in? – Easily about 4 – 5 days.

- Return period of long phases with wind power feed-in less than 8% of installed capacity:



- Longest phases observed with one week below 8%
- Extreme value theory regression for the 10% longest phases (i.e. longer than 1.4 days, N = 166)
- Quantile plot (inset) shows acceptable quality of fit
- Almost two weeks with low wind power in 100 a consistent with the data
- 95% confidence bands via percentile bootstrapping

➢ **Phases of low wind power can be longer than a week and occur every two years.**

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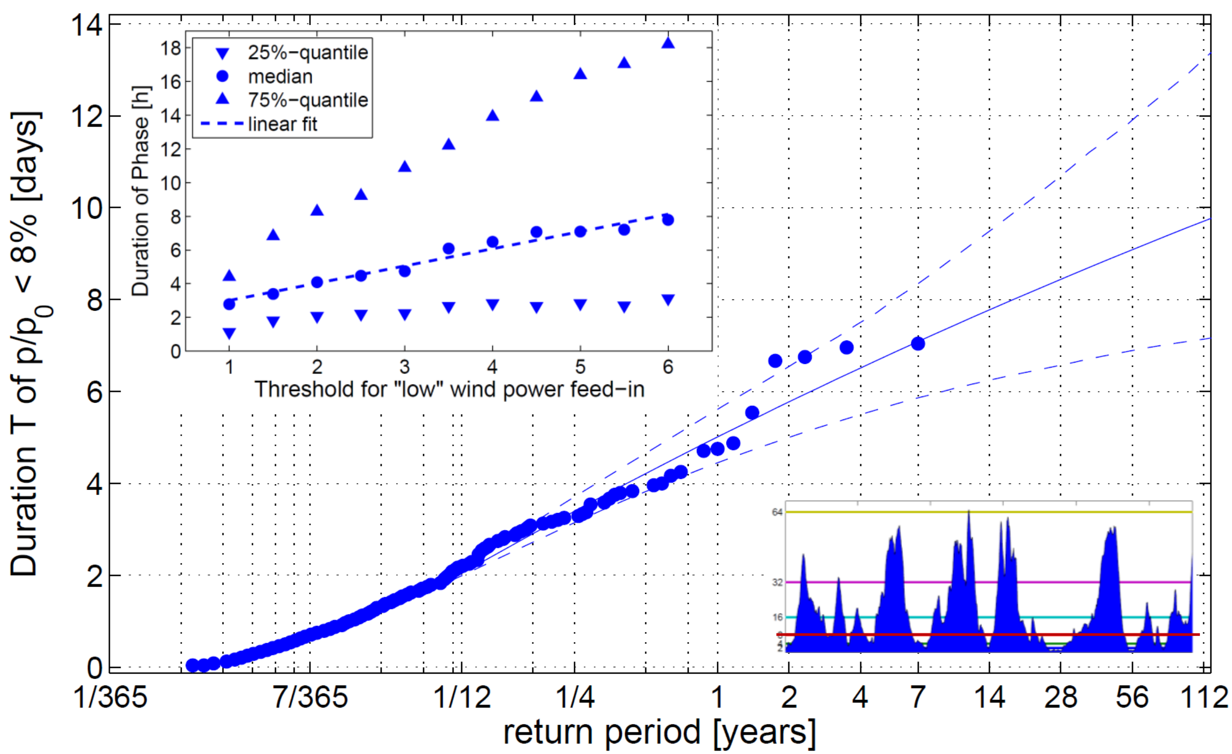

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- 95% confidence bands via percentile bootstrapping
- Duration of phases increases with threshold value: 2%: 4h & 8%: 10h

➢ **Phases of low wind power can be longer than a week and occur every two years.**

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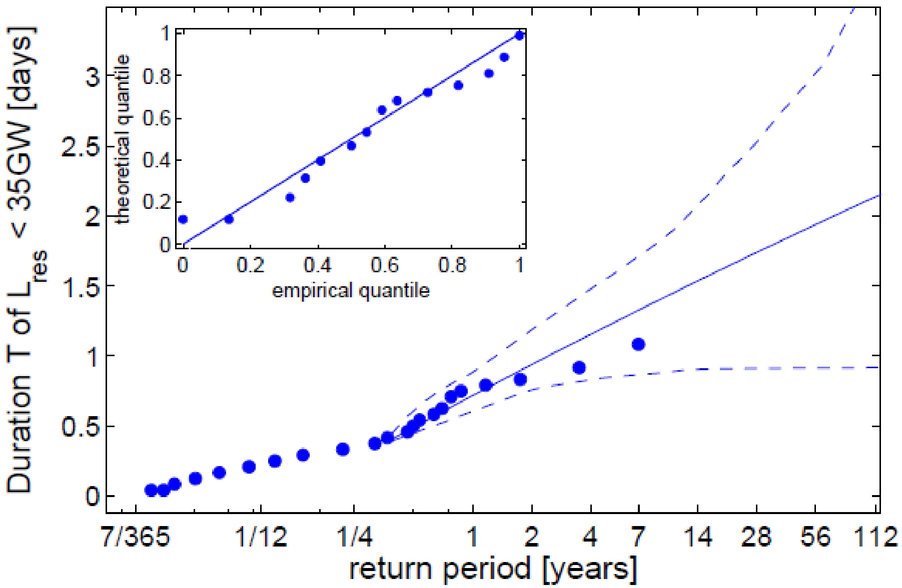
How long are phases of low residual load?

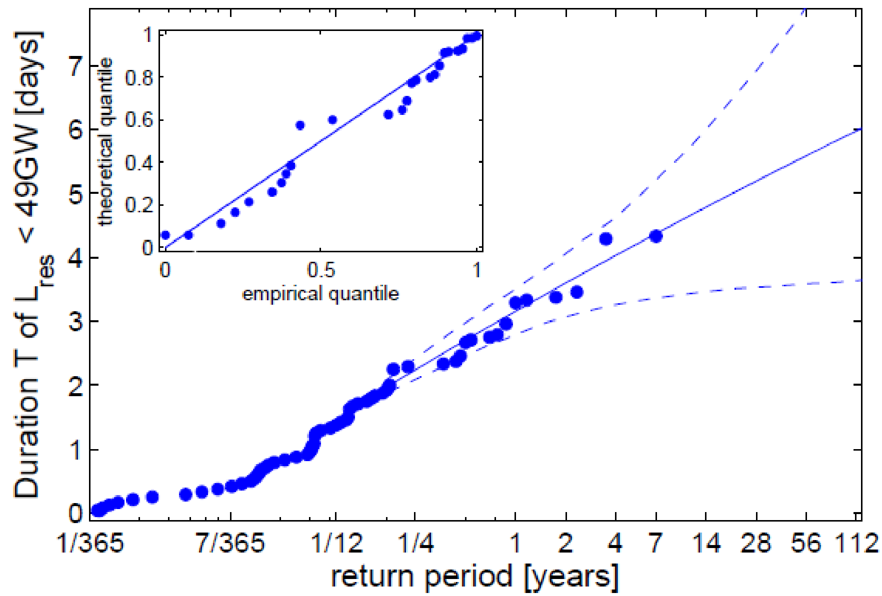
- Return period of long phases with low residual load
- Two definitions for 'low' (3% and 32% quantile)

Quantile	min	0.10	0.25	0.50	0.75	0.90	max
L_{res} [GW]	14.6	40.8	46.5	55.1	64.0	70.0	82.9

Phases of residual load < 35 GW



Phases of residual load < 49 GW



➢ **Phases of very low residual load can be longer than one day.**

Comments: Left figure: threshold for 'extreme' is 90% quantile; Right figure: threshold for 'extreme' is 97% quantile.

How typical are the years with respect to phases of low wind power feed-in?

- We measure similarity of individual years in comparison to all years

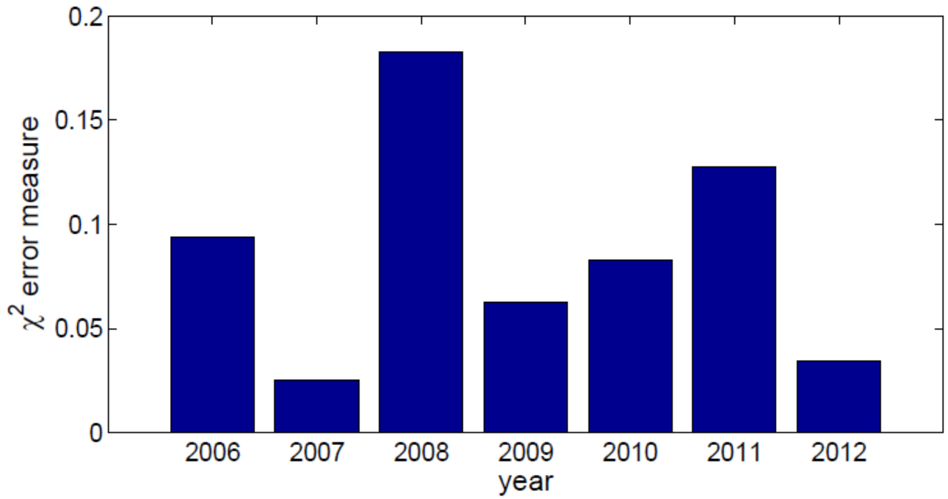
$$\chi^2 = \sum_{\text{bounds } i} \frac{(\text{observed}_i - \text{expected}_i)^2}{\text{expected}_i}$$

observed$_i$ = mean log duration below threshold i in year n
expected$_i$ = mean log duration below threshold i all years

$$\chi^2 = \sum_i (o_i - e_i)^2 / e_i$$

$$o_i = \frac{1}{n} \sum_l^n \ln(t_{li}) \quad e_i = \frac{1}{N} \sum_l^N \ln(t_{li})$$

- Low χ^2 means high similarity, high χ^2 means little similarity



- Choose phases with 1%, 1.5%, ..., 5.5%, 6%
- Chose log of durations since distributions are right-skewed
- Measure only considers duration of phases, total wind energy and residual load could be different
- Difference up to factor of 10

➤ **Years differ in duration of low wind power phases (be careful in modelling).**

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Summary and discussion

Phases of low wind power	▪ Can easily be **several days or one week** long ▪ Average **duration linear in threshold**: below p% for p+2 hours ▪ **Years differ in representativeness** of low power phase durations
Discussion	▪ Data limited to seven years in Germany (PV only one year) ▪ Growing share of wind offshore feed-in will affect residual load patterns ▪ Residual load of historical data → more spread in the future
Future work	▪ Duration of phases of low residual load for future energy system ▪ Integrate more aspects to find 'best renewable time series' for energy system modelling ▪ Only very first step in more detailed understanding of economics of energy storages and influence of duration

Contact:

More details in the paper!

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