



# How to estimate wind-turbine infeed with incomplete stock data: A general framework with an application to turbine-specific market values in Germany

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„Ökonomie der Energiewende“

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# Importance of Wind Energy

- ◆ Renewables are the fastest growing energy source on the planet.
- ◆ Most capacity additions come from intermittent sources
  - photovoltaics (74 GW in 2016)
  - wind (52 GW)
- ◆ Wind generation becomes increasingly heterogeneous
  - technological developments
  - increasing infeed has increased influence on prices



Source: Calculations based on 25,700 wind turbines in Engelhorn, Müsgens (2018)

# Research Contribution

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Answering the following questions

- ◆ Methodology: How can a wind energy converter's hourly infeed be estimated based on incomplete data?
- ◆ Structure: What is the historical development of turbine market values in Germany?
- ◆ Drivers: What influences the difference in market values observed?

# Definitions: Market Values and Performance

- ◆ Market values

$$MV_{j,y} = \frac{\sum_{h=1}^{8760} yield_{j,y,h} \cdot p_{y,h}}{\sum_{h=1}^{8760} yield_{j,y,h}}$$

$$MV_y^{fleet} = \frac{\sum_{j=1}^J \sum_{h=1}^{8760} yield_{j,y,h} \cdot p_{y,h}}{\sum_{j=1}^J \sum_{h=1}^{8760} yield_{j,y,h}} = \frac{\sum_{h=1}^{8760} yield_{y,h}^{fleet} \cdot p_{y,h}}{\sum_{h=1}^{8760} yield_{y,h}^{fleet}}$$

- ◆ Performance

$$abs\_pf_{j,y} = MV_{j,y} - MV_y^{fleet}$$

$$rel\_pf_{j,y} = (MV_{j,y} - MV_y^{fleet}) / MV_y^{fleet}$$

# „Decomposition“ of Performance

„Normalized standard deviation“,  
positive for all WECs,  
the smaller the better, decreases with  
lower  $\sigma$  or higher expected yield

$$abs\_pf_{j,y} = \sigma(p_{y,h}) \cdot \left( \boxed{cor(yield_{j,y,h}, p_{y,h})} \cdot \boxed{\frac{\sigma(yield_{j,y,h})}{E(yield_{j,y,h})}} - cor(yield_{y,h}^{fleet}, p_{y,h}) \cdot \frac{\sigma(yield_{y,h}^{fleet})}{E(yield_{y,h}^{fleet})} \right)$$

Correlation between hourly yield  
and wholesale price,  
negative for all WECs in sample,  
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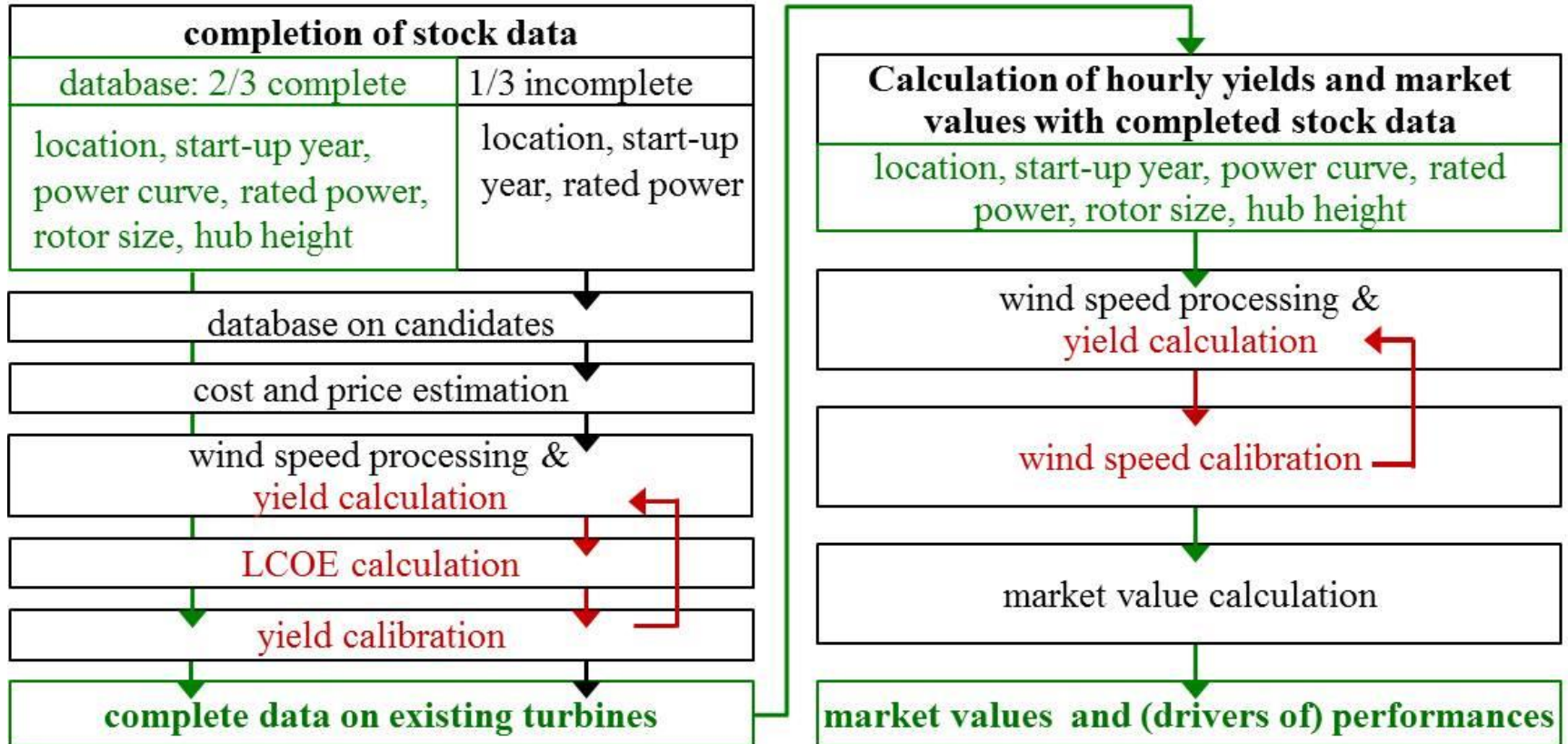
$$abs\_pf_{j,y} = \sigma(p_{y,h}) \cdot \left( \boxed{cor(yield_{j,y,h}, p_{y,h})} \cdot \boxed{\frac{\sigma(yield_{j,y,h})}{E(yield_{j,y,h})}} - \boxed{cor(yield_{y,h}^{fleet}, p_{y,h})} \cdot \boxed{\frac{\sigma(yield_{y,h}^{fleet})}{E(yield_{y,h}^{fleet})}} \right)$$

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# Empirical Challenge

- ◆ Estimate hourly yields of >25,000 wind energy converters (WECs) in Germany:  $yield_{j,y,h} = PC_j(v^*) \cdot l_j$
- ◆ Necessary information:
  - The *number of WECs* deployed in a system.
  - The *power curves* of the WECs. Each WEC has a model name from a WEC manufacturer, and each model name features a distinct power curve given in its technical specifications.
  - The *hub heights* of the WECs. Unlike the power curve, height is not set in the model name as each model is usually available in at least two different heights.
  - The *locations* of the WECs (longitude, latitude).
  - *Hourly wind speeds* at the WEC positions (i.e. locations and hub heights).

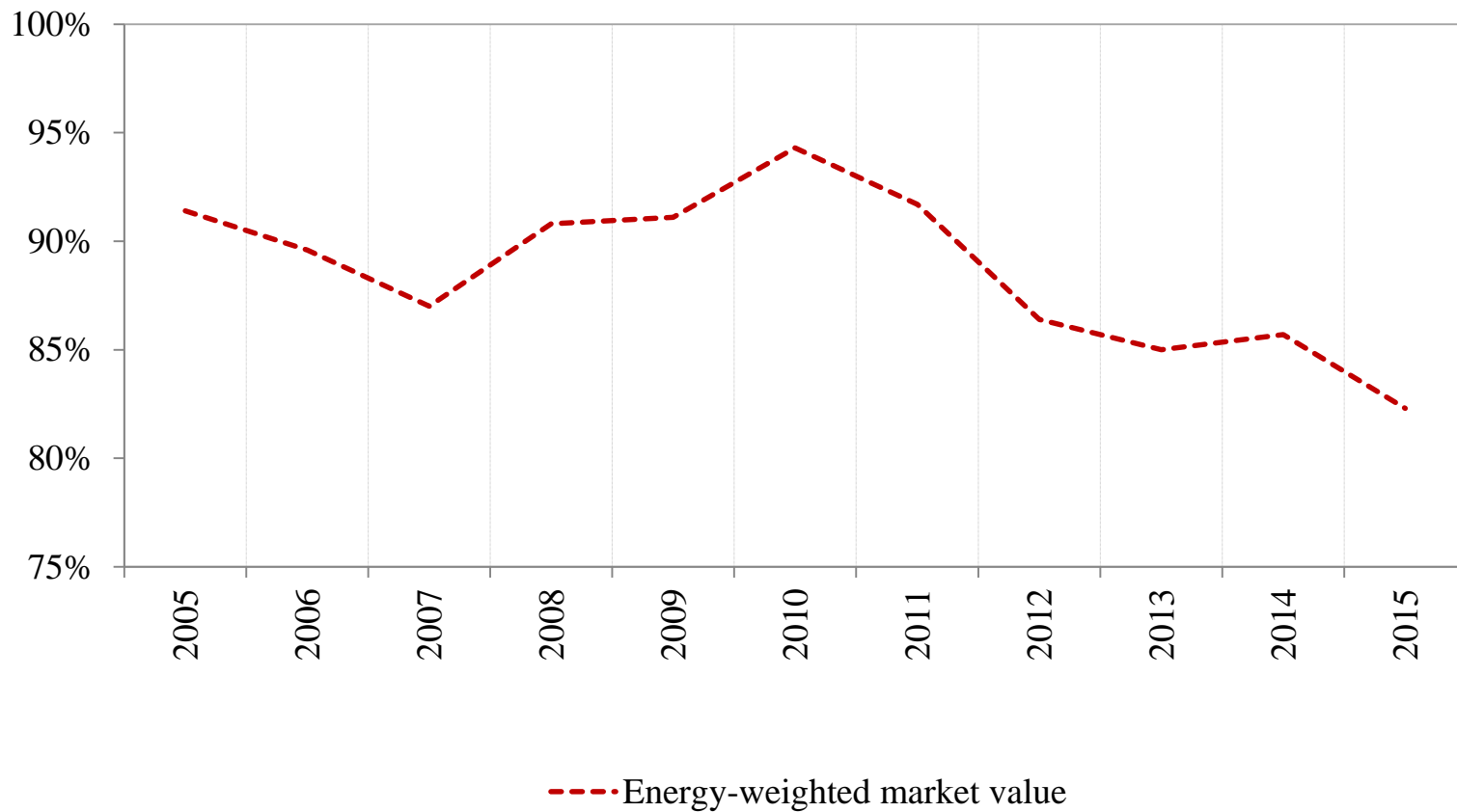
# Method to complete stock data and its application to model market values.



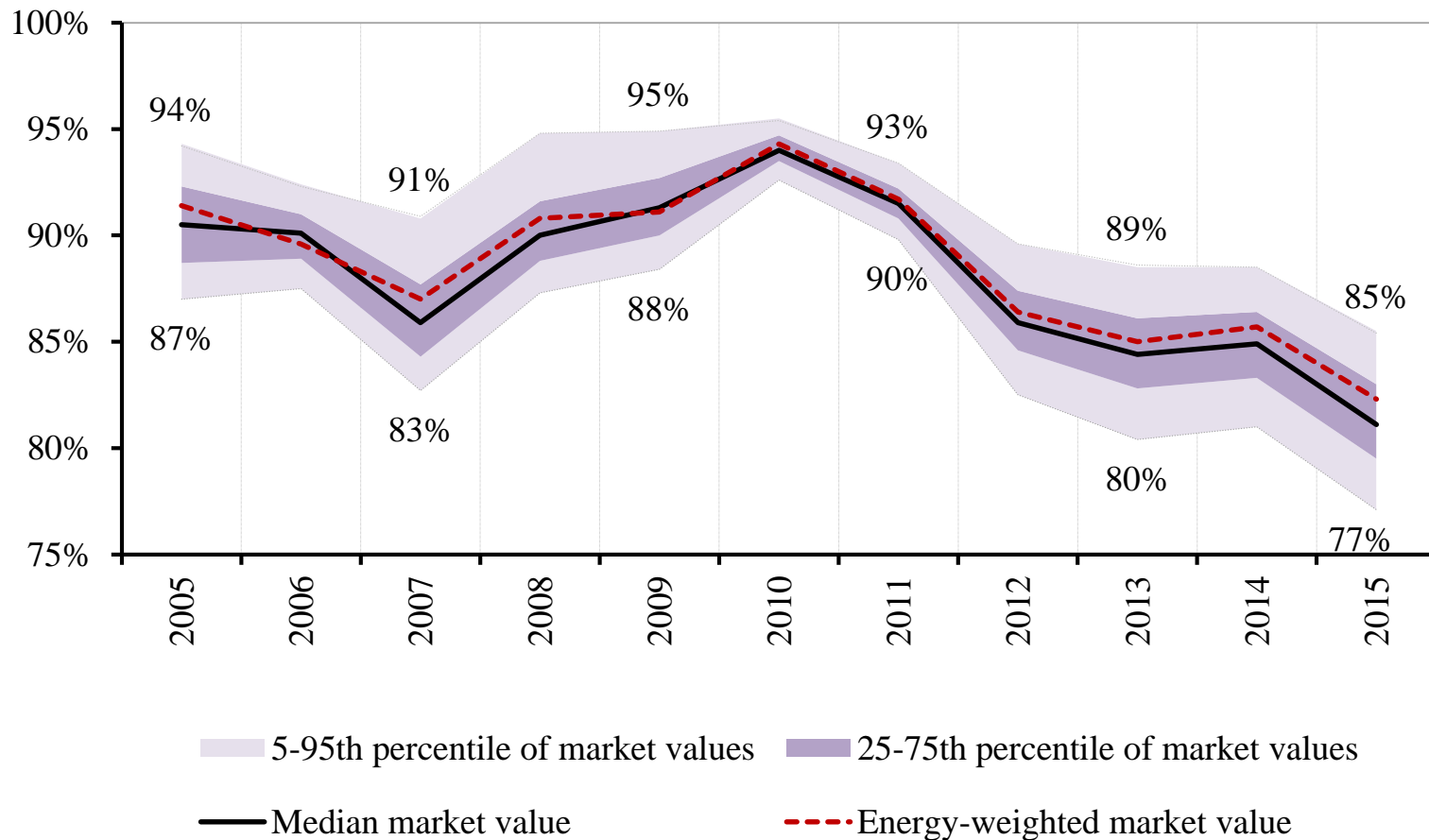


# Results

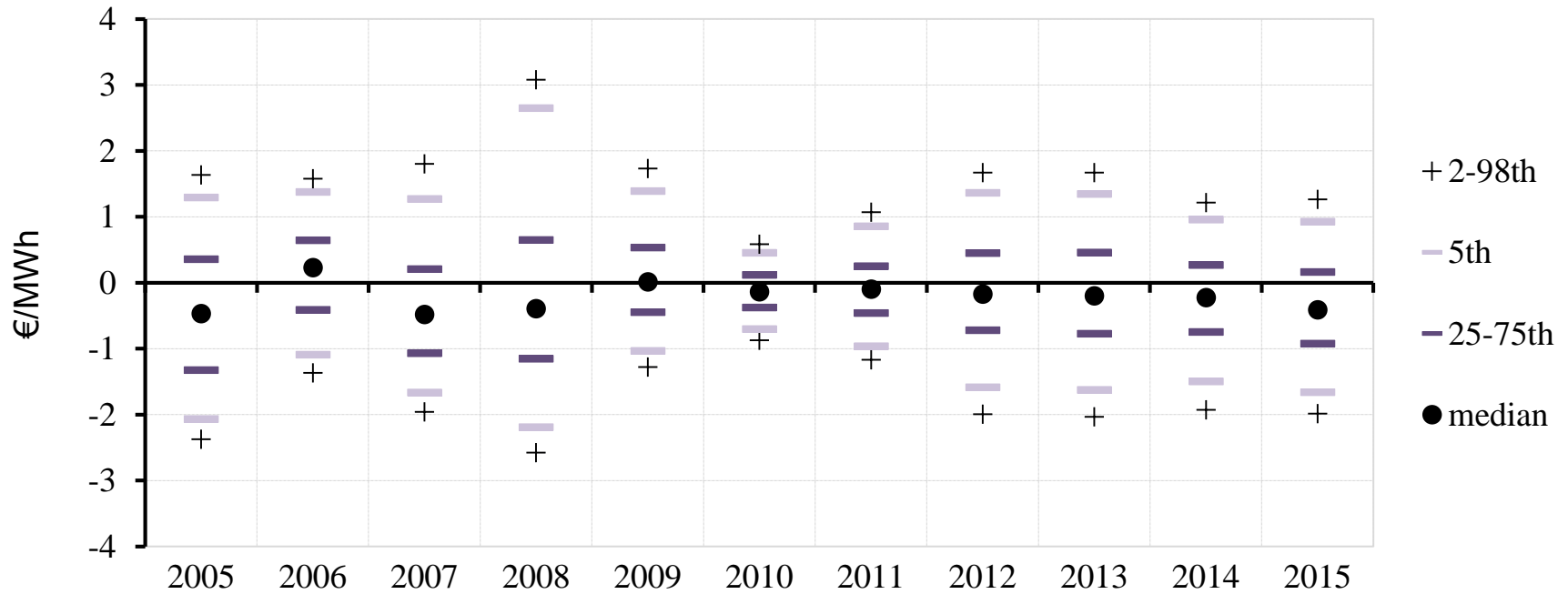
# Percentiles of market value [% of average wholesale prices] – aggregated data



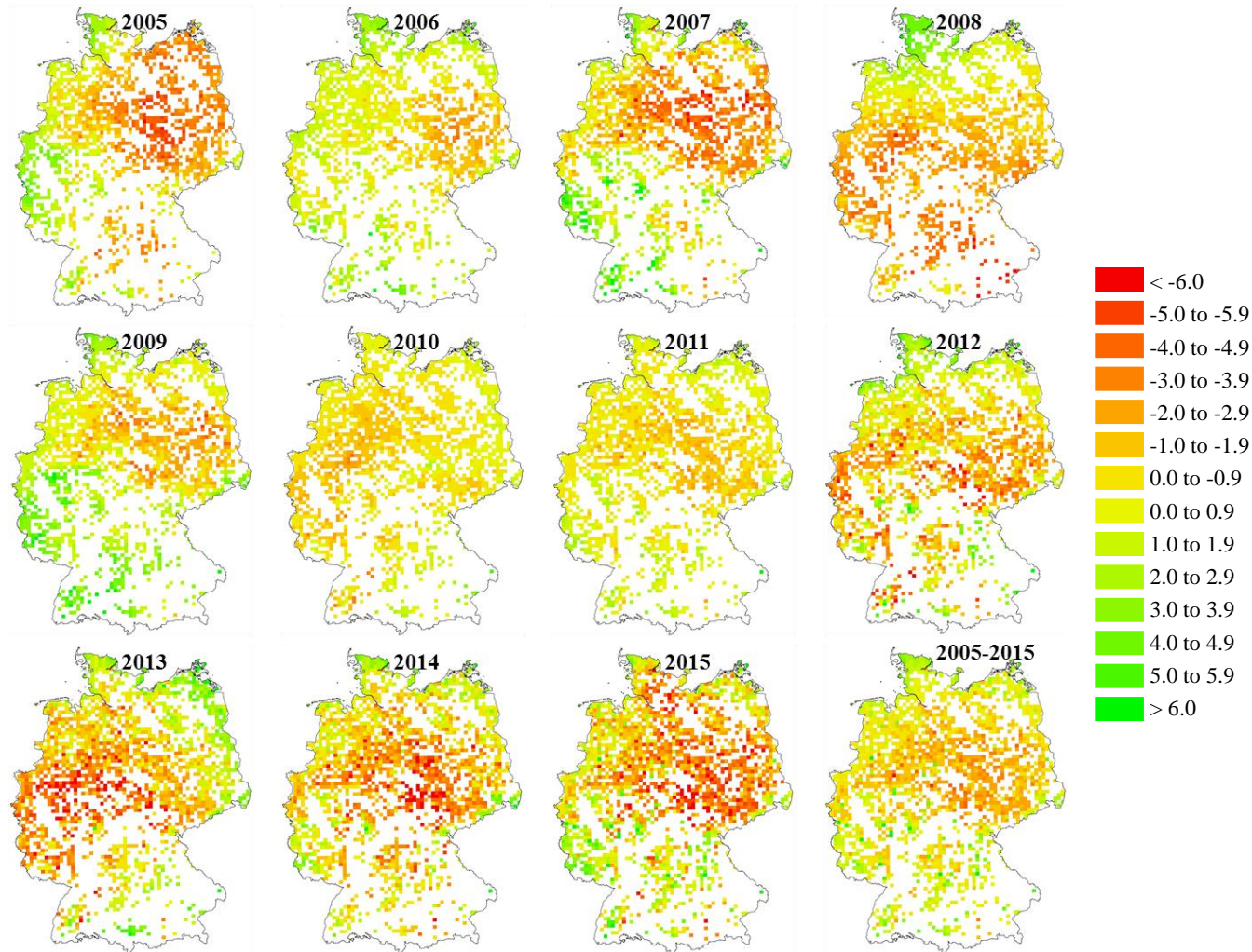
# Percentiles of market value [% of average wholesale prices] – our disaggregated data



# Percentiles of absolute performance, years 2005–2015

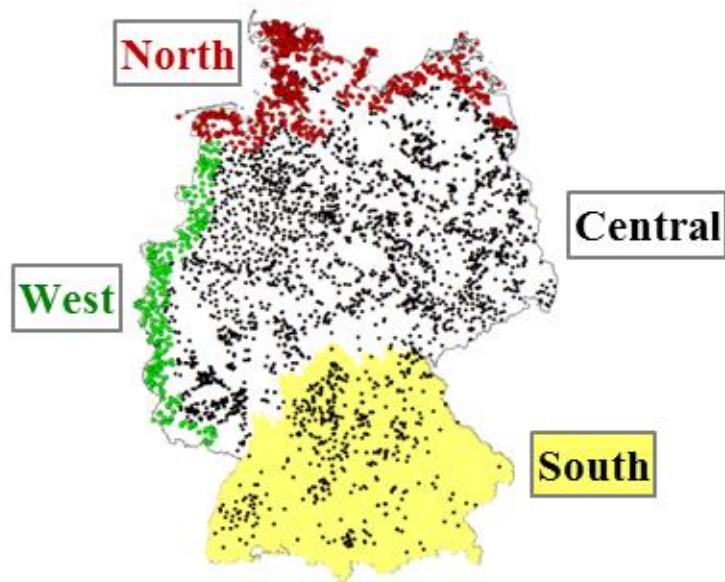


# Regional variation of relative performance [%]

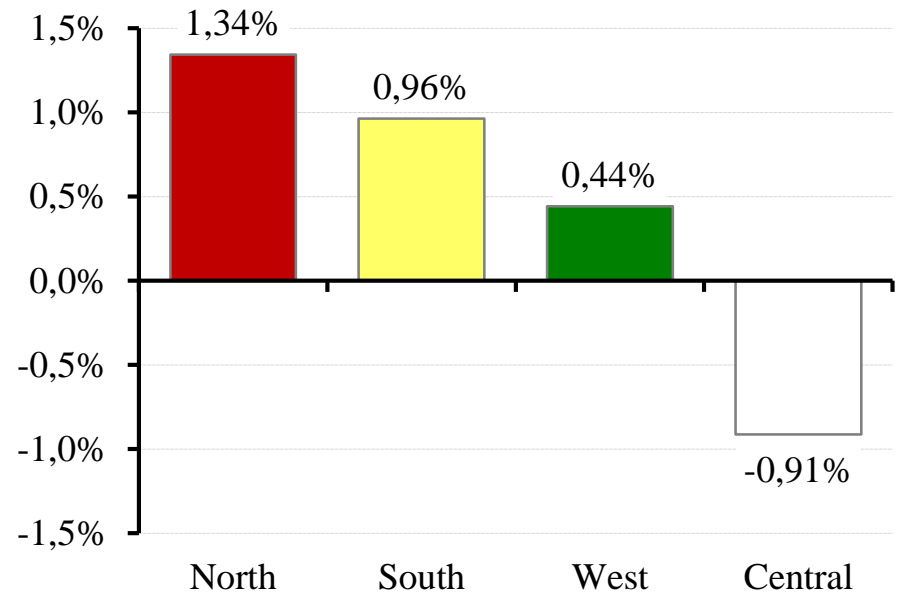


# Regional Analysis of Performance

Illustration of regional clusters

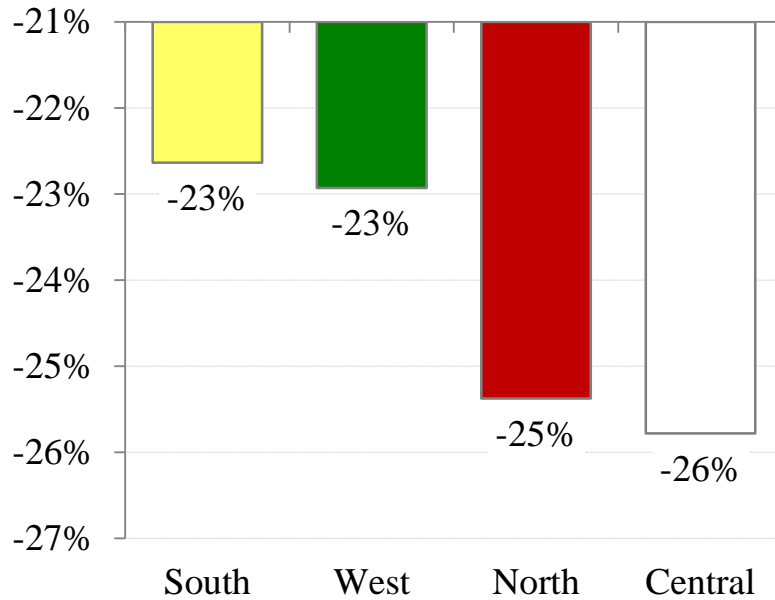


Average relative performance in regional clusters

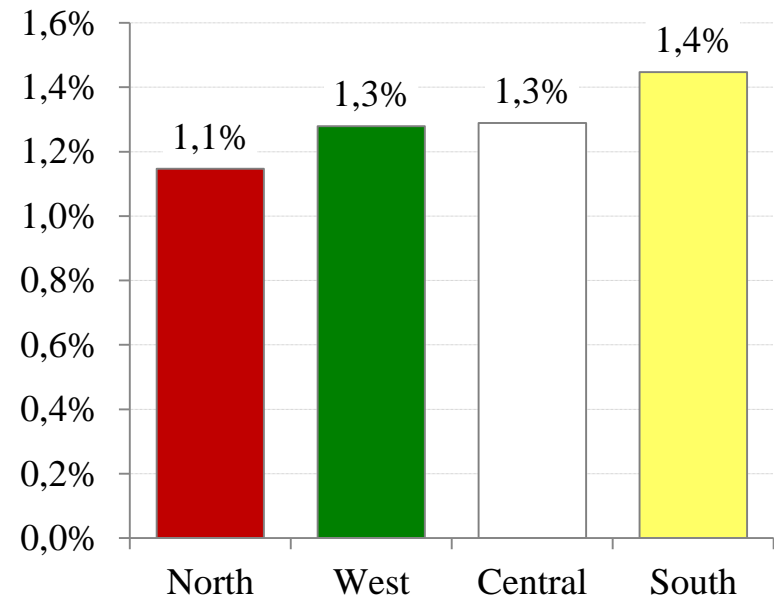


# Decomposition of regional effects

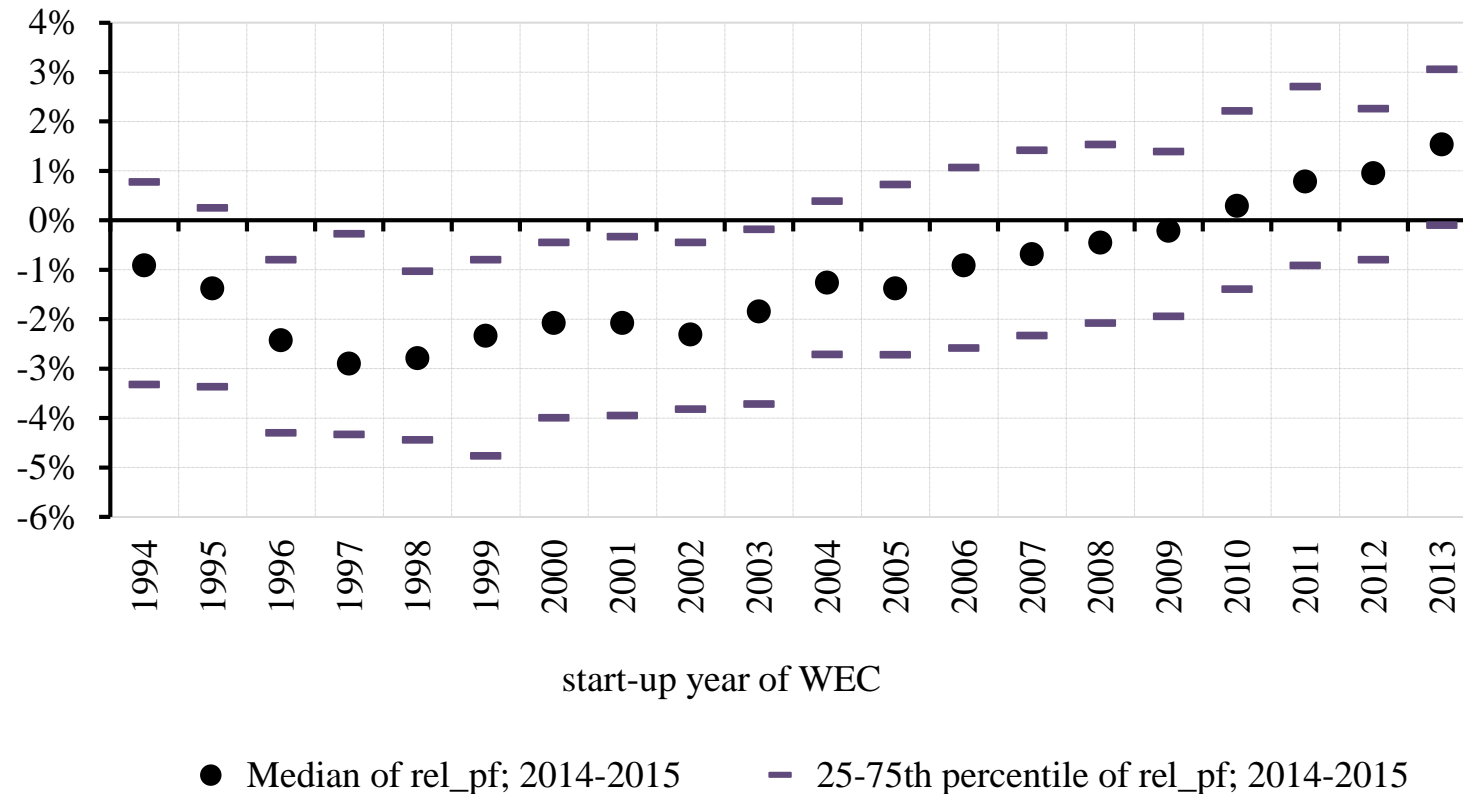
### Correlation



### Normalized standard deviation

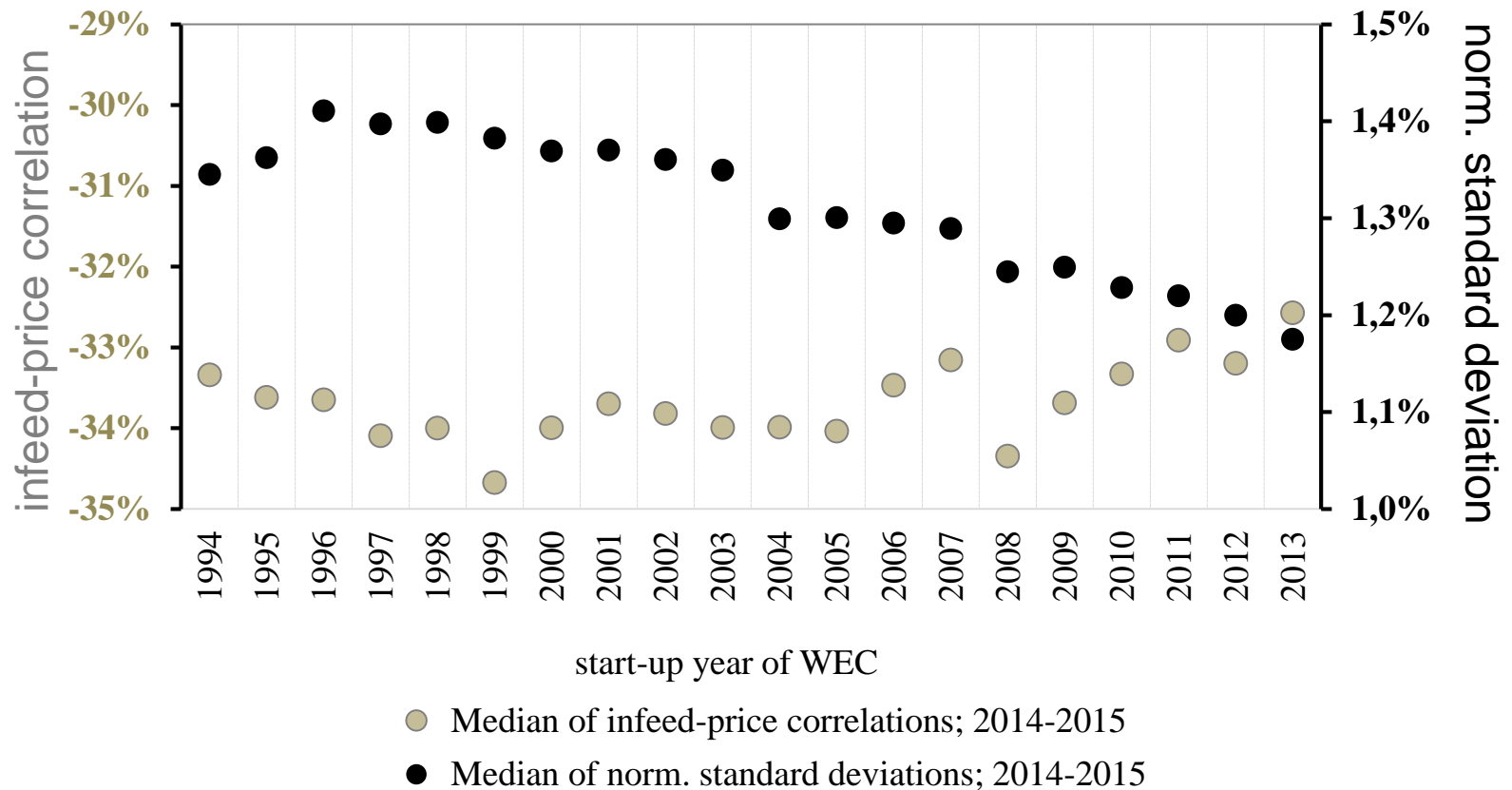


# Relative performance by WEC generations





# Decomposition: Performance by WEC generations



# Last but not least

- ◆ Extensive online appendix publicly available:
  - Data on 25,700 WECs
    - turbine type, rated power, rotor diameter, hub height, commissioning date, TSO, state, wind zone (class), city, postcode, location height, geo code
    - Relative performances (market values) by year (2005 to 2015)
  - Turbine data
    - power curves for 188 models, rated power, rotor diameter, available hub heights, market availability, wind class, capex
- ◆ Potential further research:
  - E.g. performances by hub height, rotor diameter, capacity factors
  - Disaggregation of market value in two components: the location and the technology (and possibly, the technology further into hub height and specific rating)

# Sources

- ◆ Engelhorn, T. und Müsgens, F. (2017): „How to estimate wind-turbine infeed with incomplete stock data: A general framework with an application to turbine-specific market values in Germany“, *Energy Economics*, <https://doi.org/10.1016/j.eneco.2018.04.022>, in press.



Thank you.  
Questions?

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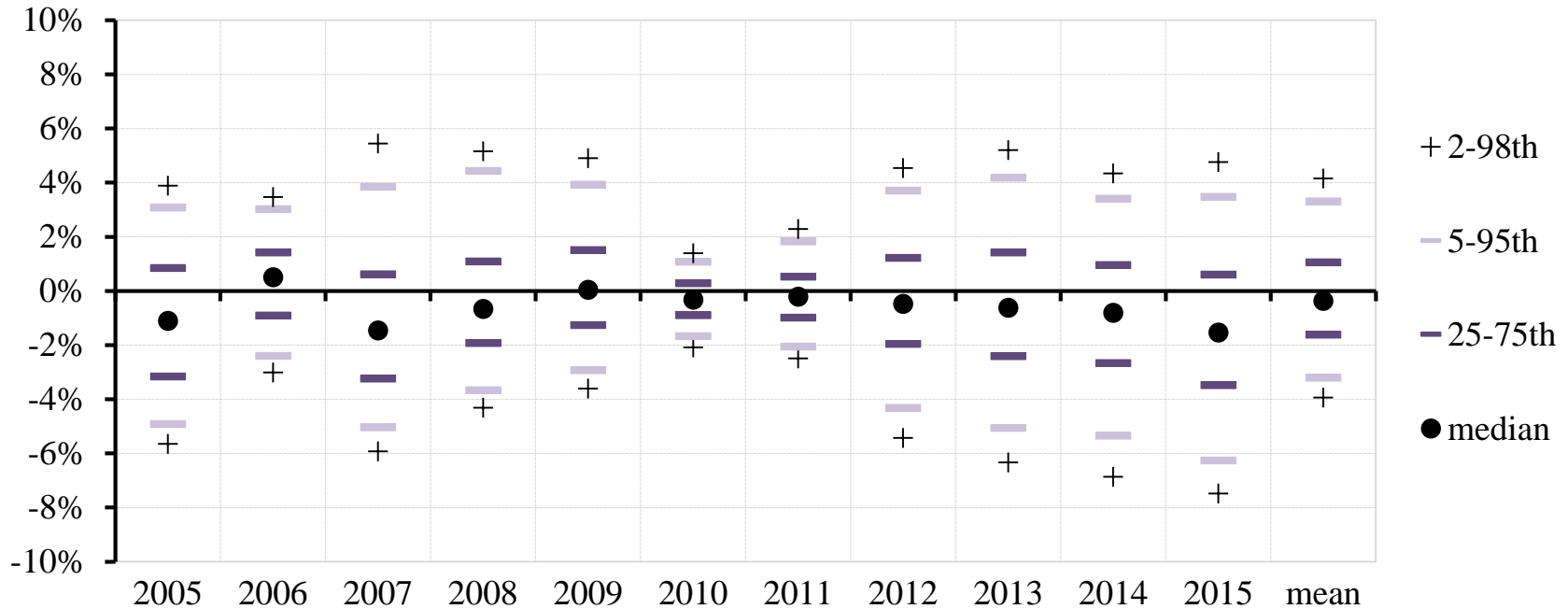
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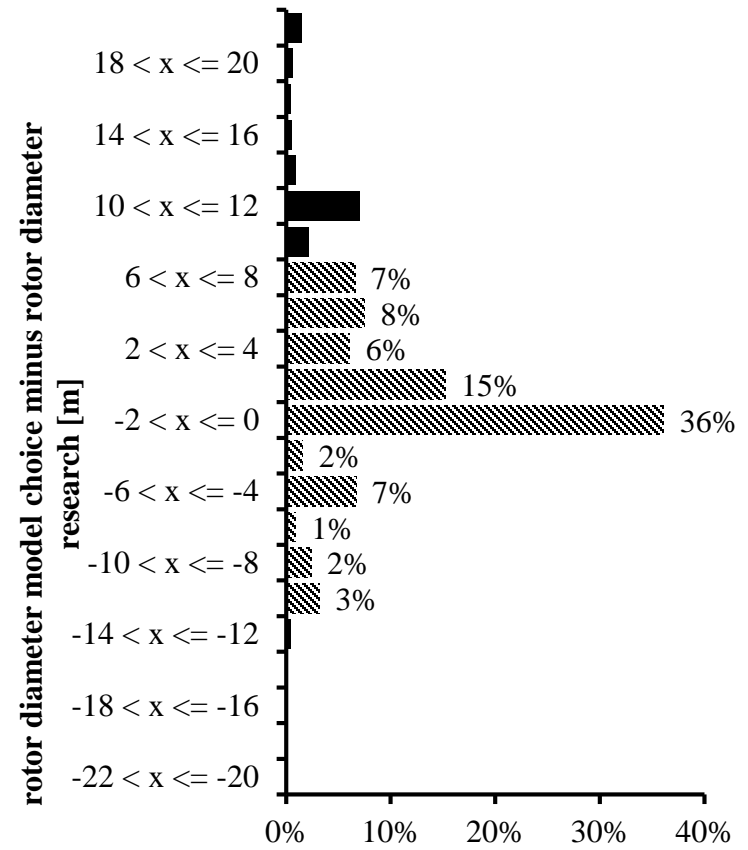
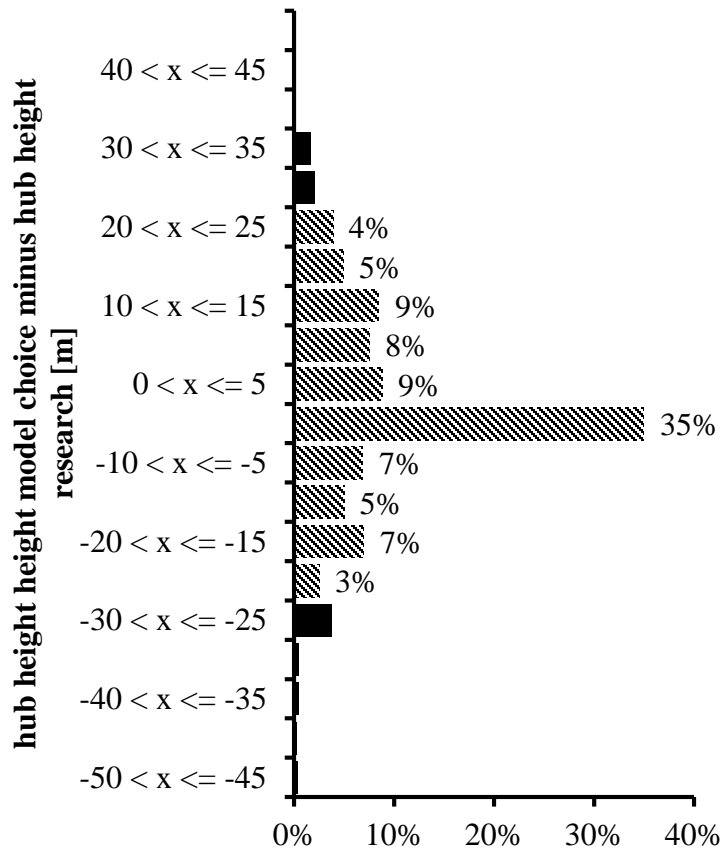
<https://www.b-tu.de/fg-energiewirtschaft/>

# Percentiles of relative performance, years 2005–2015 and mean of all years

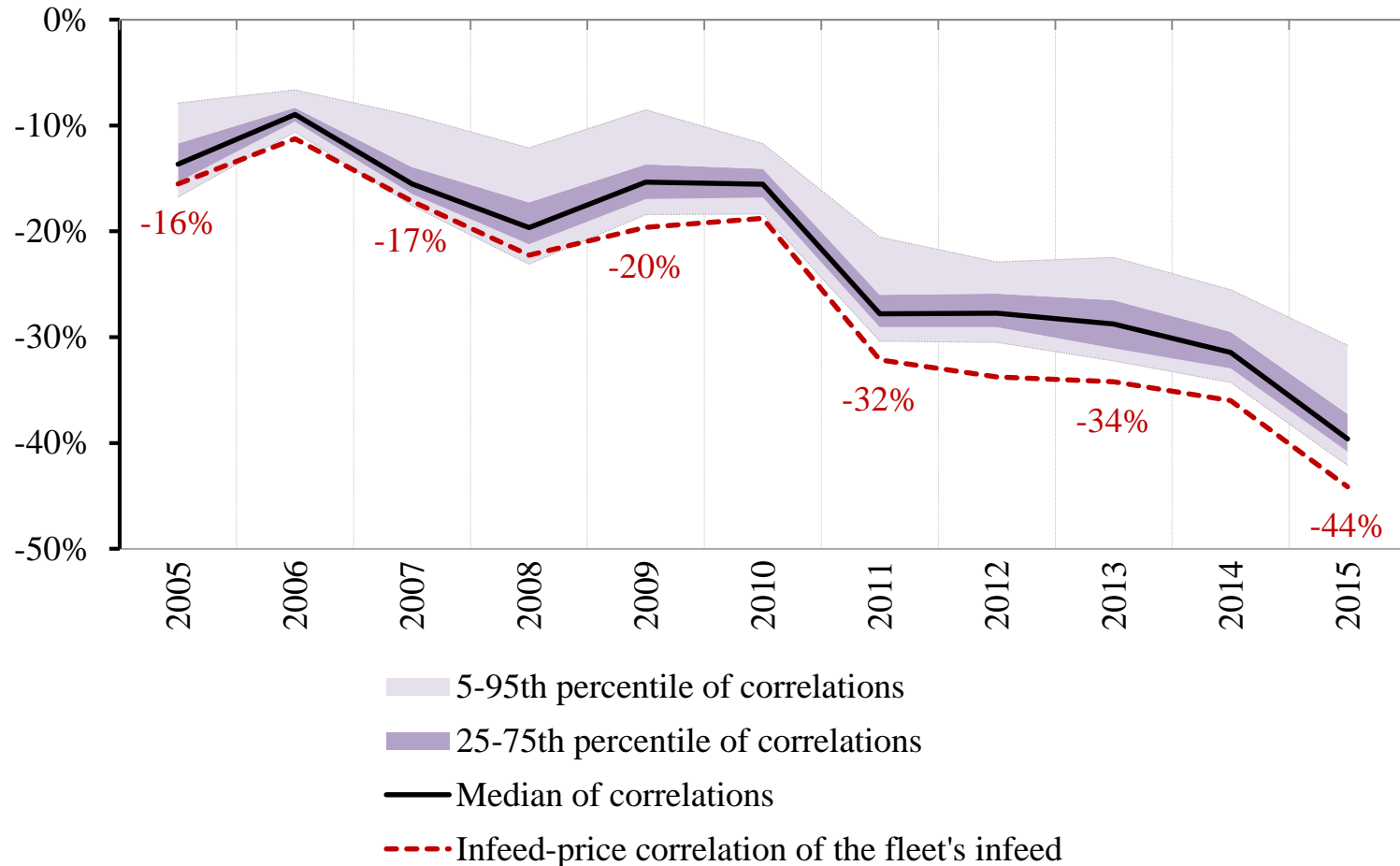


- ◆ In some cases, deviations between highest and lowest relative performances can exceed 10%-points.
- ◆ Note that this difference translates above average into profits.

# Model quality: turbine choice

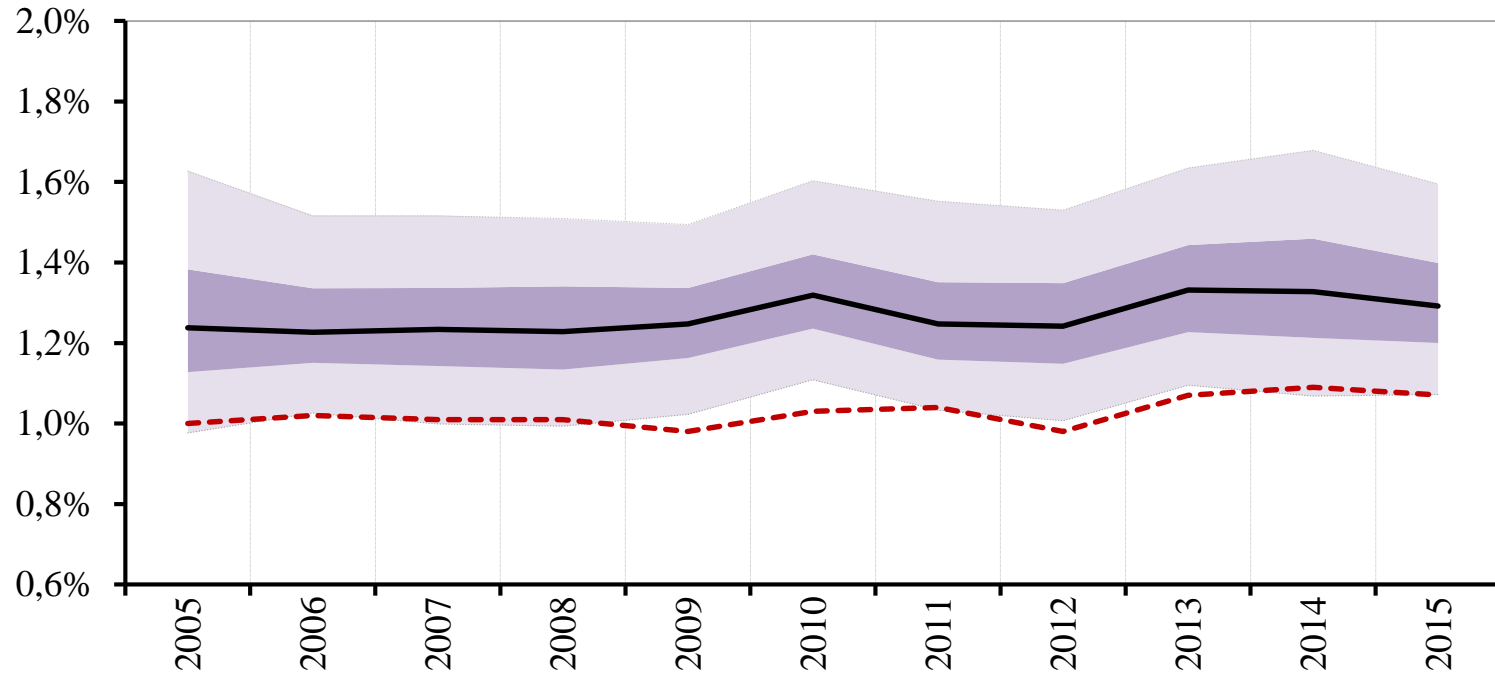


# Infeed-price correlations



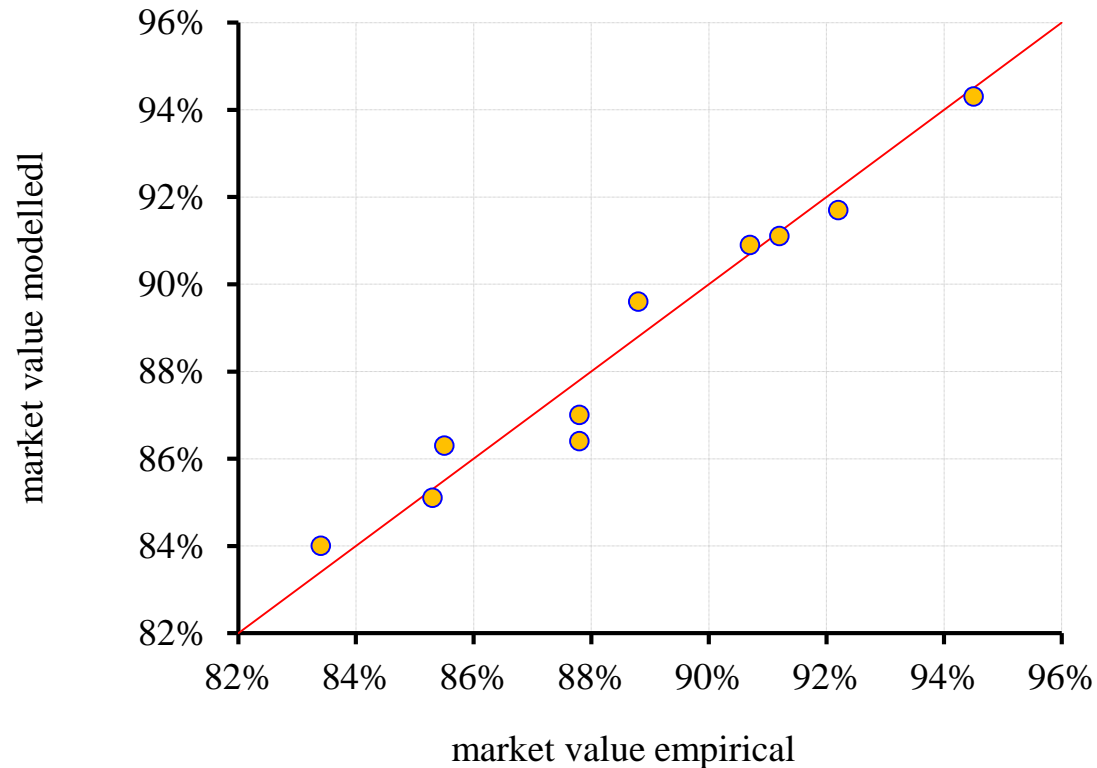


# Normalized Standard deviations

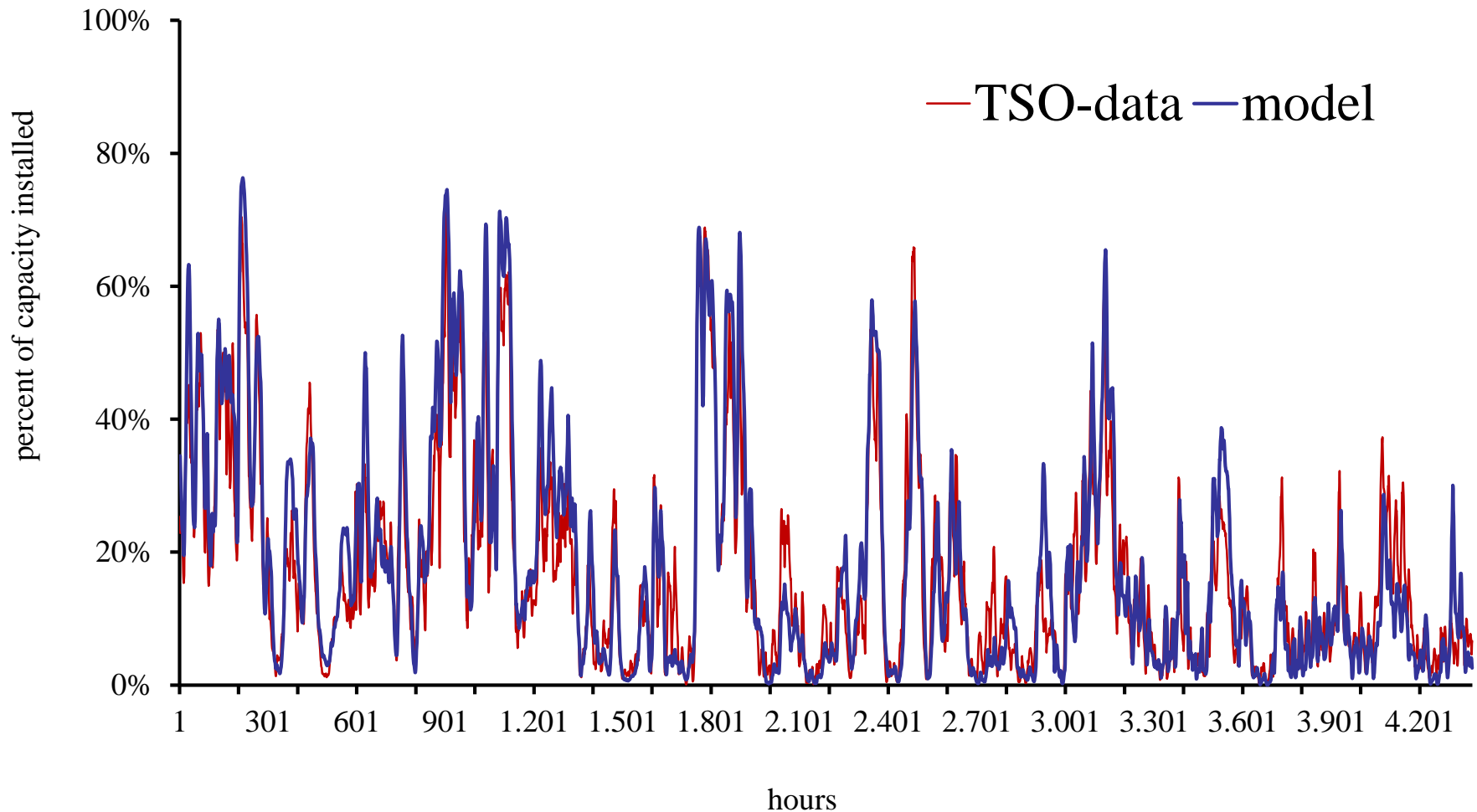


- 5-95th percentile of standard deviations
- 25-75th percentile of standard deviations
- Median of standard deviations
- Standard deviation of the fleet's infeed

# Model quality: market values of the fleet



# Model quality: hourly infeed profile, first half of 2014



# Model quality: correlogram, distribution, step-change

