TECHNISCHE UNIVERSITÄT DRESDEN

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The Effect of Offshore Wind Capacity Expansion on Uncertainties in Germany's Day-Ahead Wind Energy Forecasts

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Session 1E: Renewables I – Wind
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Agenda

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1. **Motivation**

   Why do we care about the effects of offshore wind capacity expansion?

2. **Data description**

3. **Descriptive analysis of wind speed forecast errors**

   Are offshore and onshore locations exposed to different wind speed forecast errors?

4. **Model-based evaluation of the effect of offshore capacity expansion**

   What are the effects of offshore wind capacity expansion on day-ahead wind energy uncertainties?

Motivation

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Background

- Growing shares of wind energy capacities, not only in Germany but across Europe
- Substantial **offshore wind energy** capacities added since 2013
- Wind speed prediction errors affect day-ahead wind energy predictions, and thus **day-ahead decisions** (e.g. unit commitment) and **energy system adjustments** during all hours of the day

Offshore wind characteristics

1. Geographically concentrated capacities → Simultaneously affected by prediction errors
2. Oceanic conditions and large hub heights → Exposure to higher wind speeds
3. Cubic relationship $P \sim v^3$ → Greater effect of wind speed deviations at medium/high speeds

Does offshore wind capacity expansion lead to different day-ahead wind energy uncertainties?

Data description: European Centre for Medium-Range Weather Forecasts (ECMWF)

Highly resolved wind speed data (0.125° by 0.125°)

CAMS Near-real time

- Wind speed forecasts at 12:00 on previous day
- For 9 timesteps: 0:00, 03:00, … 24:00
- Height: 10m
- Interpolation for the remaining time steps

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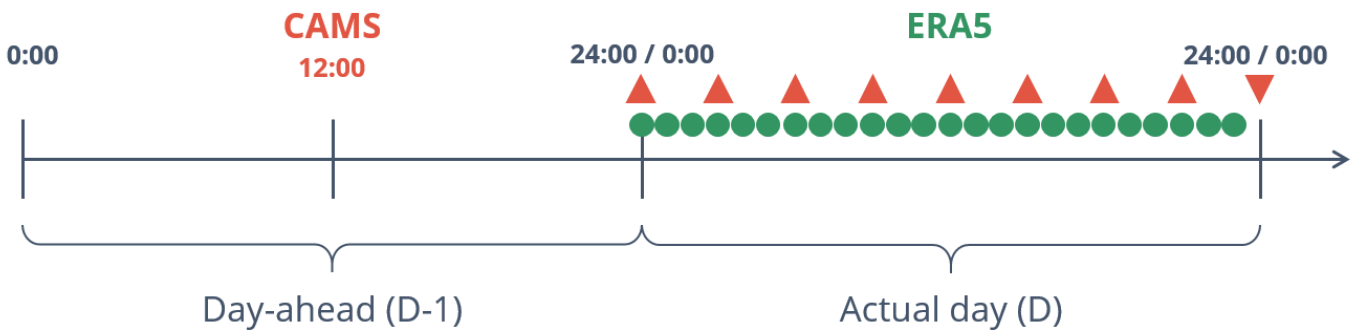
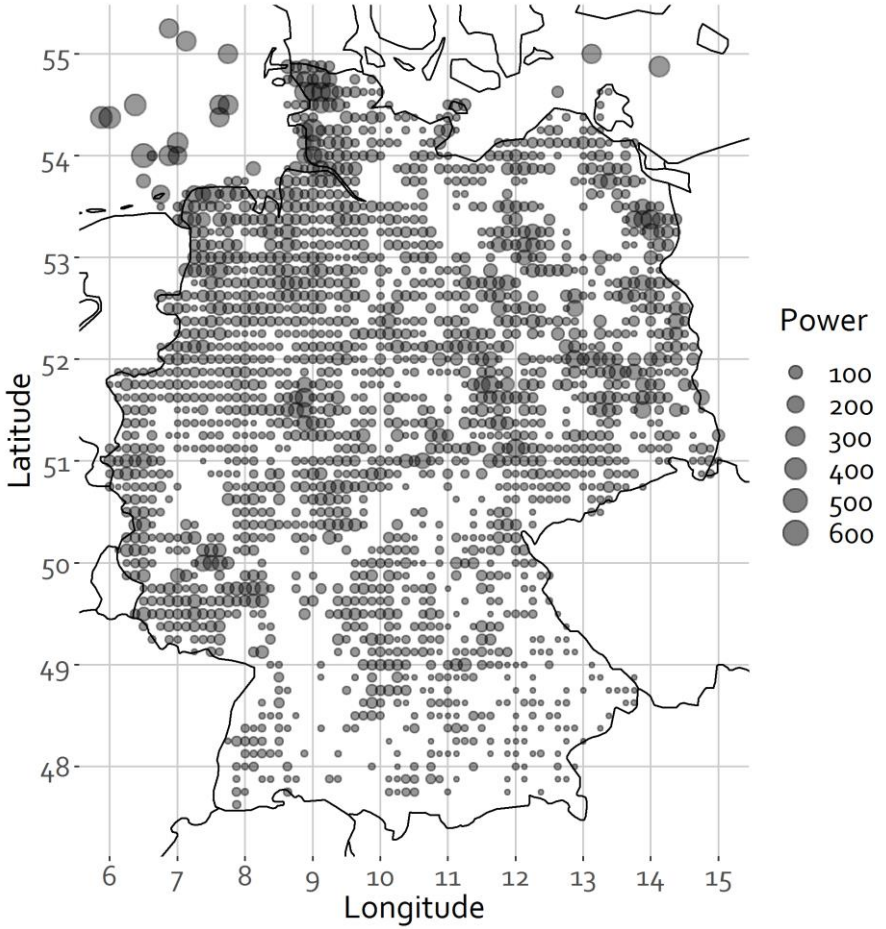
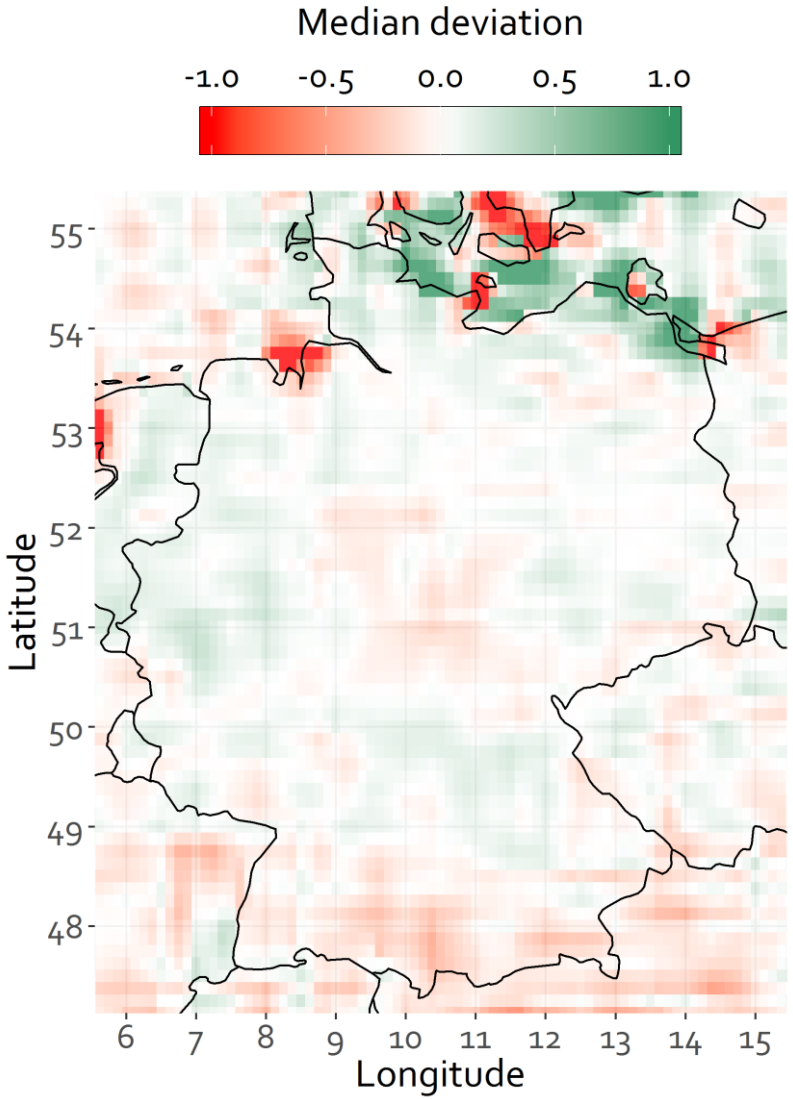
- Hourly values of actual (reanalysis) wind speeds
- Heights: 10m and 100m
- Calculation of roughness values for locations by means of logarithmic wind profile



Capacity data

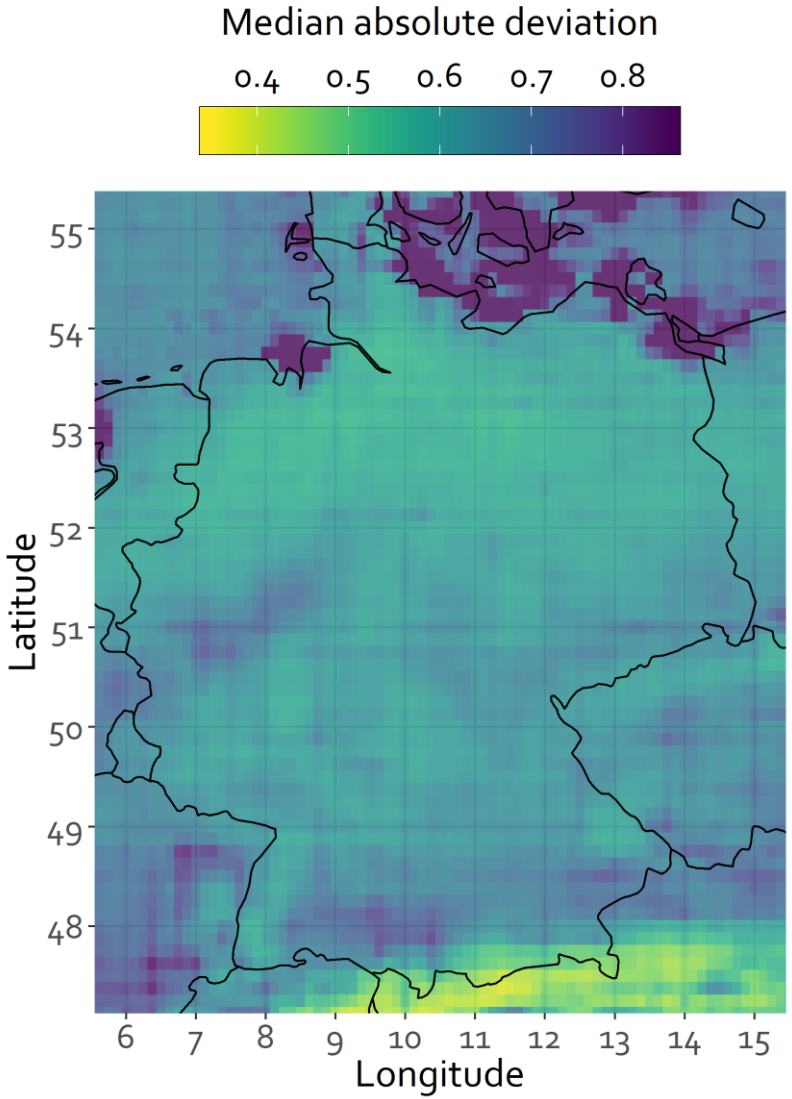


Descriptive analysis of local wind speed forecast errors (1)



(1) <u>Systematic</u> deviations only for offshore without capacities and near-shore locations

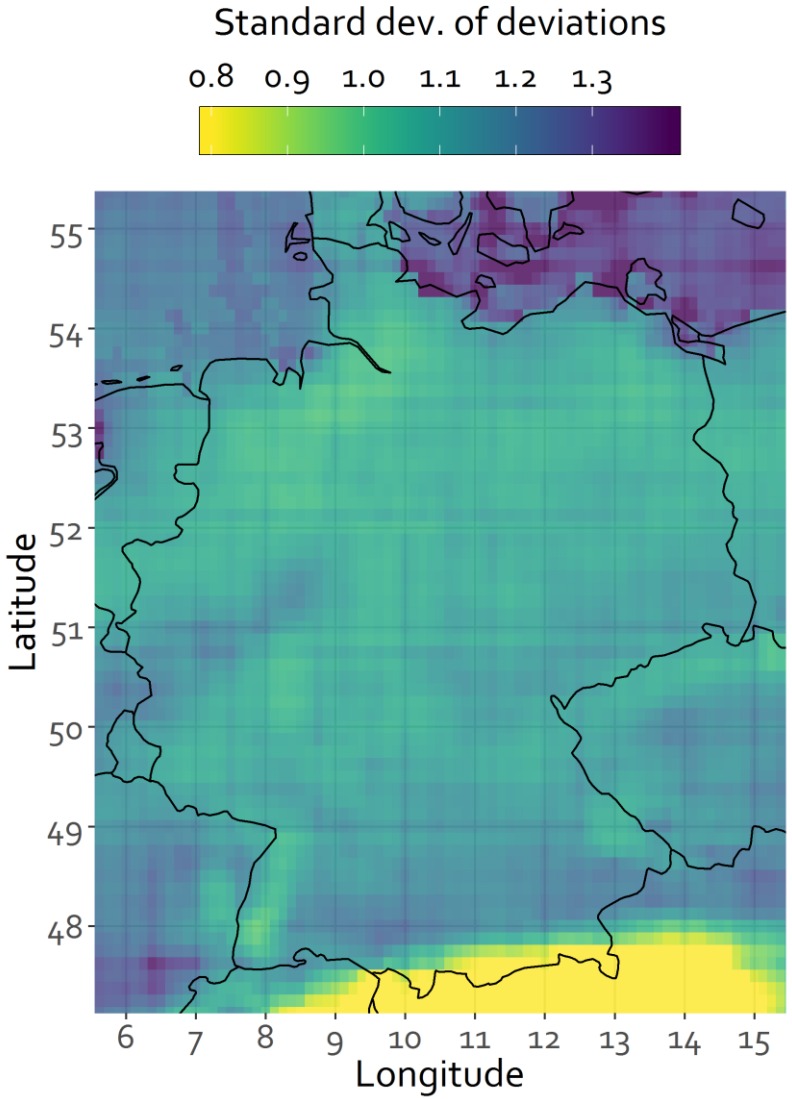
Descriptive analysis of local wind speed forecast errors (2)



(1) Systematic deviations only for offshore without capacities and near-shore locations

(2) Slightly higher average errors for offshore locations with capacities and substantially higher for near-shore

Descriptive analysis of local wind speed forecast errors (3)

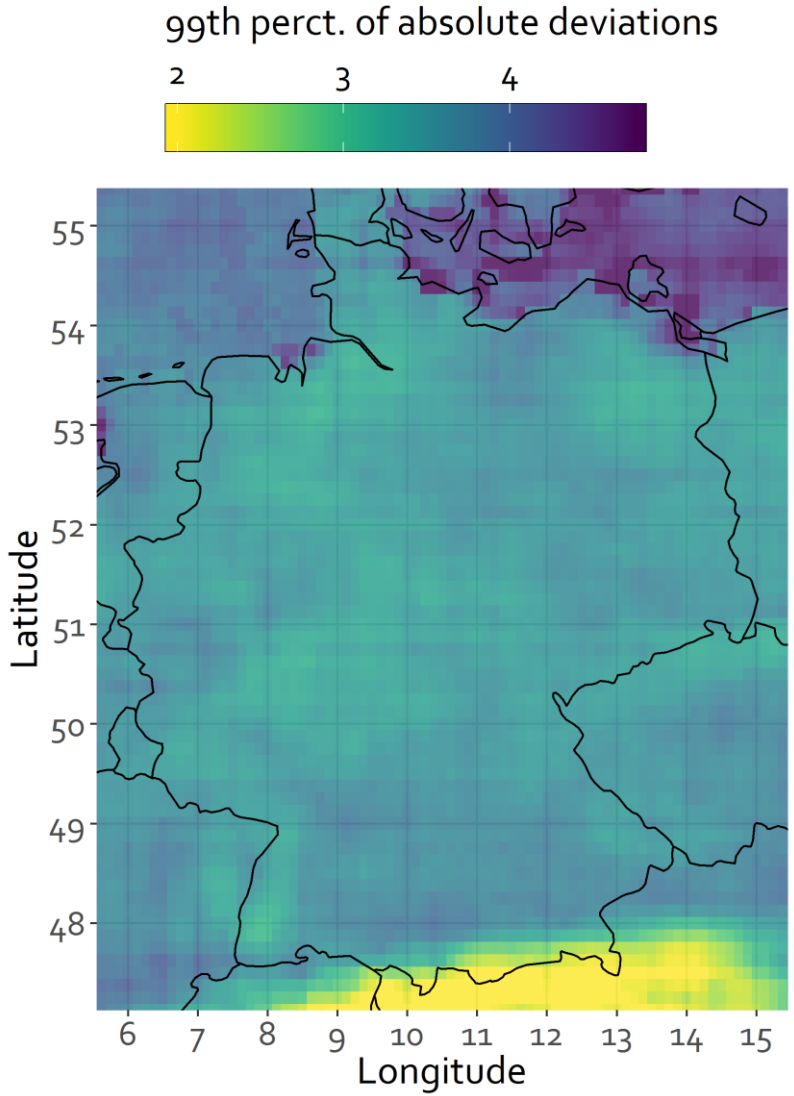


(1) Systematic deviations only for offshore without capacities and near-shore locations

(2) Slightly higher average errors for offshore locations with capacities and substantially higher for near-shore

(3) Higher variance of deviations offshore and near-shore

Descriptive analysis of local wind speed forecast errors (4)



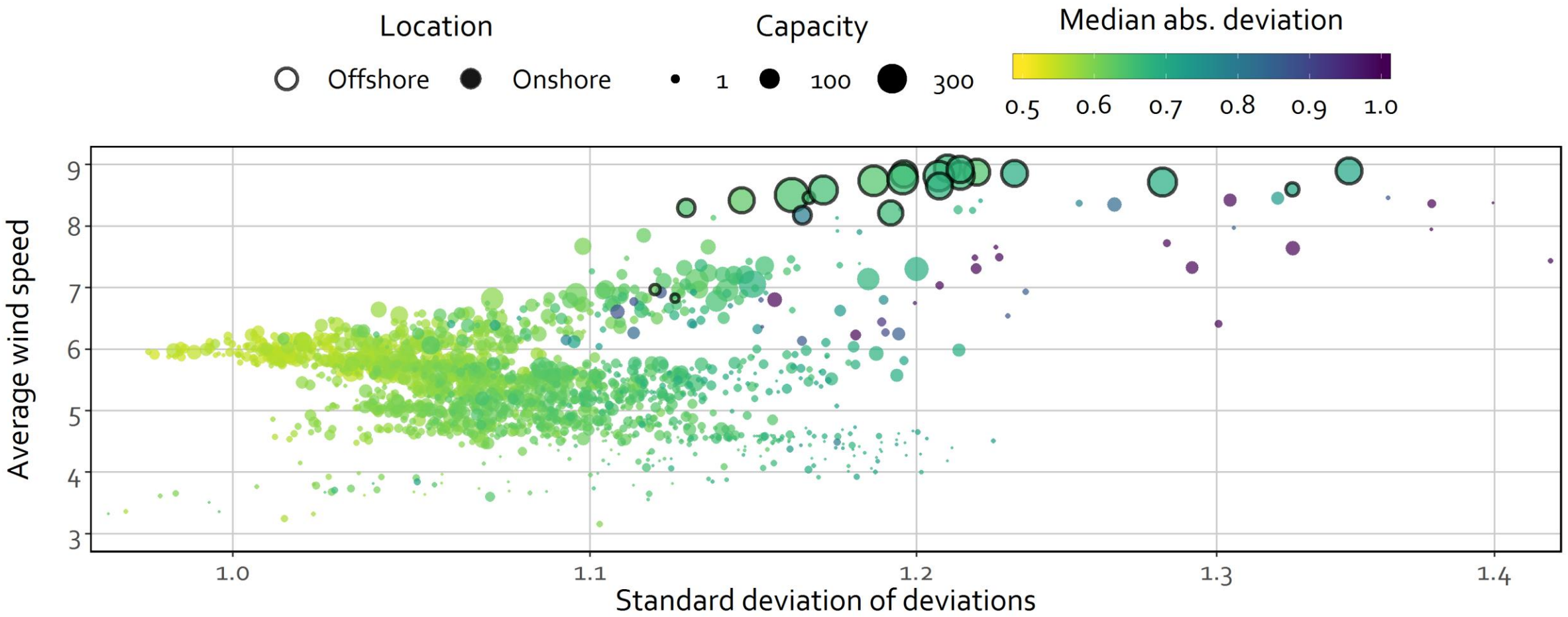
(1) Systematic deviations only for offshore without capacities and near-shore locations

(2) Slightly higher average errors for offshore locations with capacities and substantially higher for near-shore

(3) Higher variance of deviations offshore and near-shore

(4) Slightly higher extreme error magnitude for offshore locations with capacities and substantially higher for some near-shore locations

Offshore turbines are more concentrated, subject to higher wind speeds and greater and more variable wind speed forecast errors



Research question: How does offshore wind capacity expansion affect uncertainties in Germany's day-ahead wind energy forecasts?

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Input

- Hourly (*t*) local wind speed time series at capacity-weighted hub height of location *i*
- Wind energy capacities

Extremely Randomized Trees Model (Extra Trees)

- Transformation of input into aggregated wind energy, separately for
  - Forecast wind speeds
  - Actual wind speeds
- Trained using ENTSO-E data: Jan. – Sep. 2018
- Stratified sampling

$$P_t = \sum_i (\theta_{0,i} + \theta_{1,i} \cdot v_{i,t} + \theta_{2,i} \cdot v_{i,t}^2) \cdot C_i$$

Variables *resemble* a binomial, parametric model of power curves

Evaluation

→ Evaluation of deviations between wind energy forecasts and actual values

Three cases for wind capacities

1. Base case
2. Additional 5 GW offshore wind capacity
3. Additional 5 GW onshore wind capacity

Hyperparameter configuration of Extra Trees model

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Root mean squared errors (RMSEs) for test and training set (in parentheses) and duration of model training (in seconds) for different hyperparameters

Cross-Validation	Maximum Features	Number of Estimators	Maximum Leaf Nodes				
			100	500	1000	5000	10,000
3-fold	250	50	2459 (2257) 33 s	1955 (1278) 36 s	1773 (919) 45 s	1681 (737) 70 s	1667 (737) 73 s
3-fold	250	250	2441 (2241) 83 s	1913 (1251) 157 s	1744 (883) 213 s	1640 (690) 338 s	1641 (691) 340 s
3-fold	1000	50	2347 (2099) 73 s	1860 (1143) 127 s	1741 (848) 164 s	1647 (721) 269 s	1618 (721) 260 s
3-fold	1000	250	2339 (2086) 313 s	1806 (1116) 620 s	1668 (811) 805 s	1586 (674) 1326 s	1603 (675) 1276 s
3-fold	2500	50	2306 (2030) 162 s	1804 (1079) 299 s	1665 (818) 391 s	1621 (711) 617 s	1633 (704) 628 s
3-fold	2500	250	2280 (2013) 762 s	1775 (1056) 1464 s	1651 (779) 1940 s	1600 (669) 3050 s	**1597 (668)** 3119 s

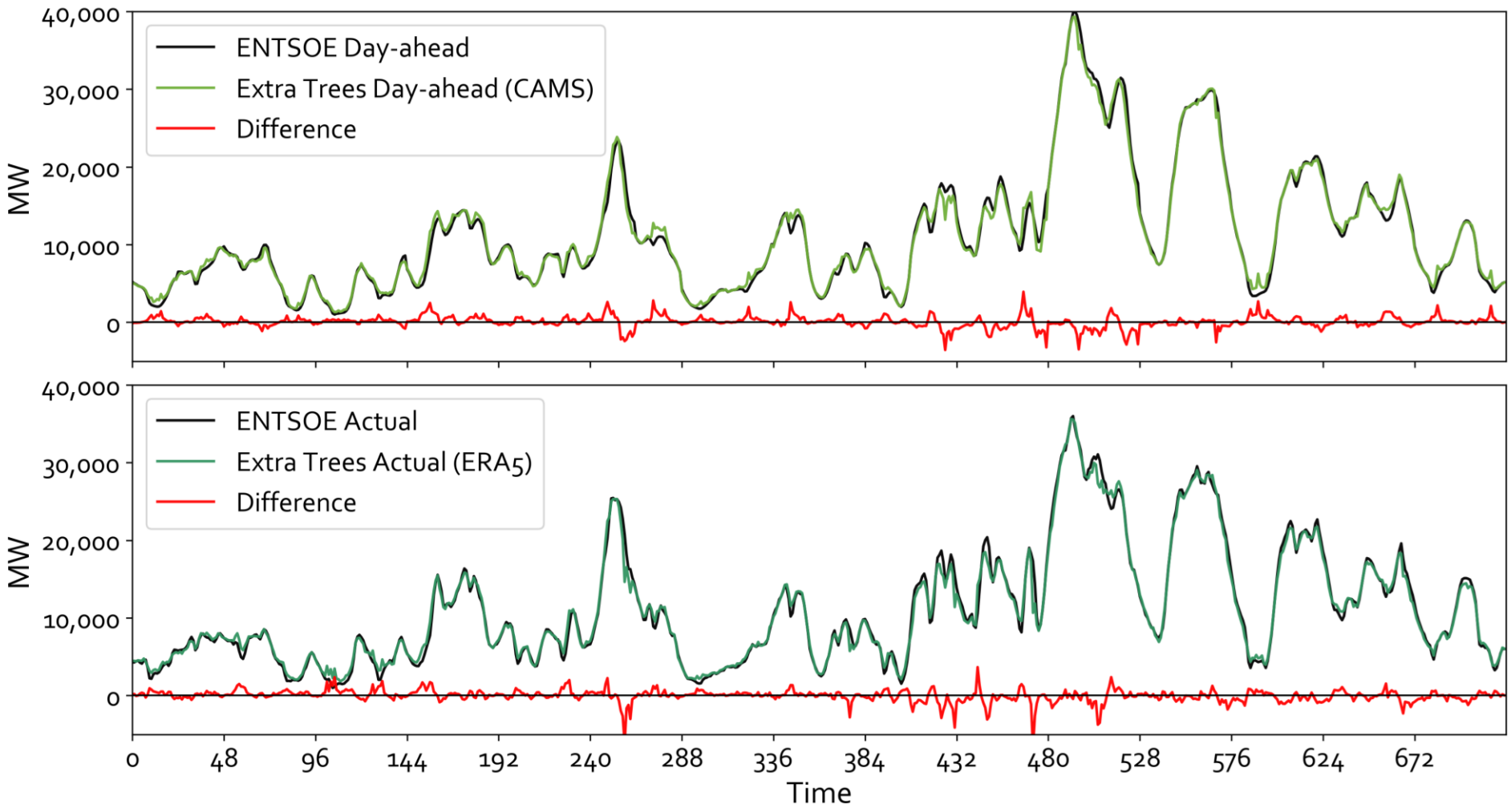
Model performance

- Extra Trees model performs well for transforming wind speeds and capacities into wind energy amounts
- RMSE relative to installed capacity
  - Training set: 0.7%
  - Test set: 1.8%
- Note that these results correspond to stratified sampling; performance on consecutive out-of-sample time series could be inferior

Exemplary performance of Extra Trees Model

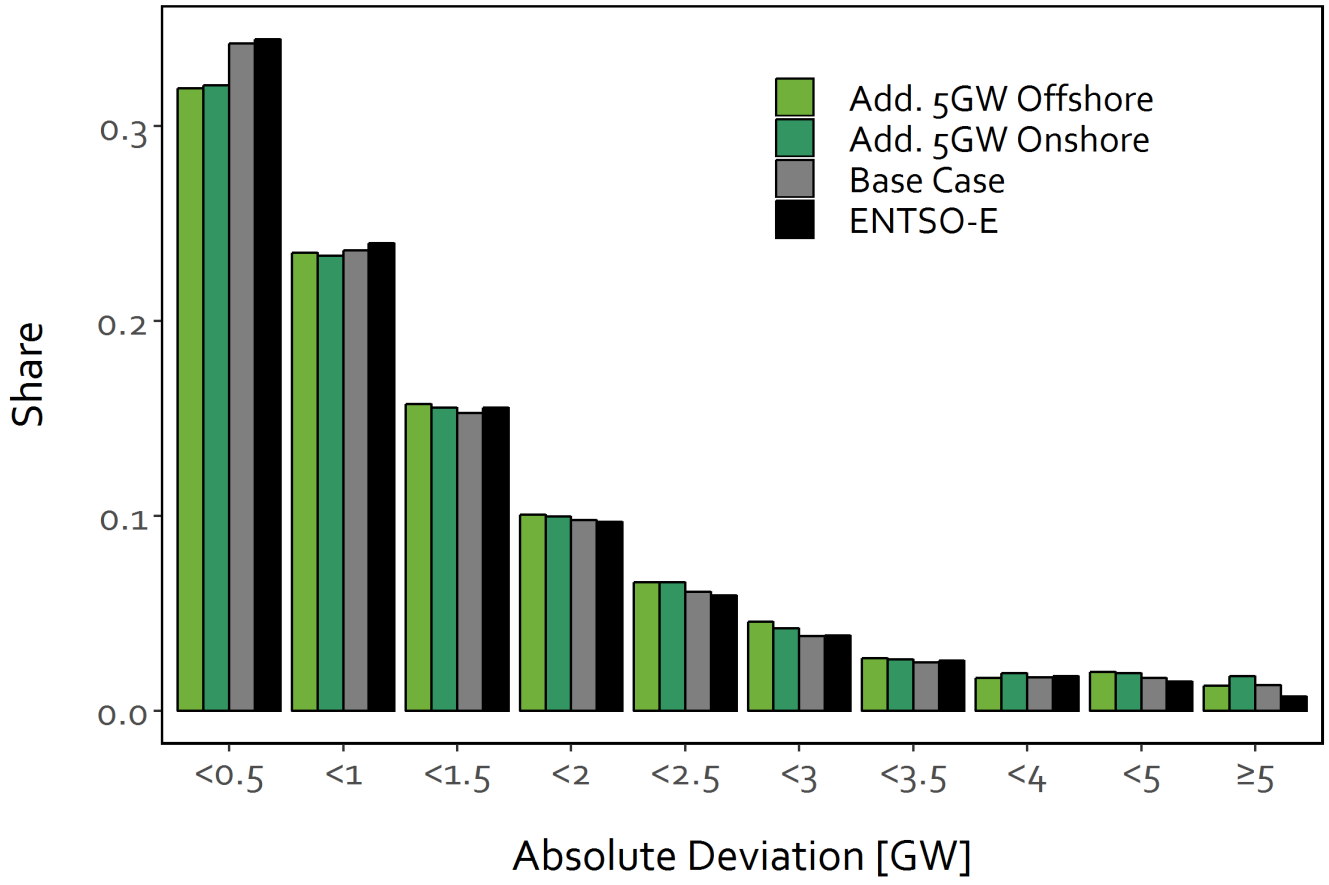
Forecast values
CAMS day-ahead wind speed forecasts transformed into day-ahead wind energy amounts

Actual values
ERA5 actual wind speeds transformed into actual wind energy amounts



Offshore wind capacity expansion leads to greater day-ahead uncertainties

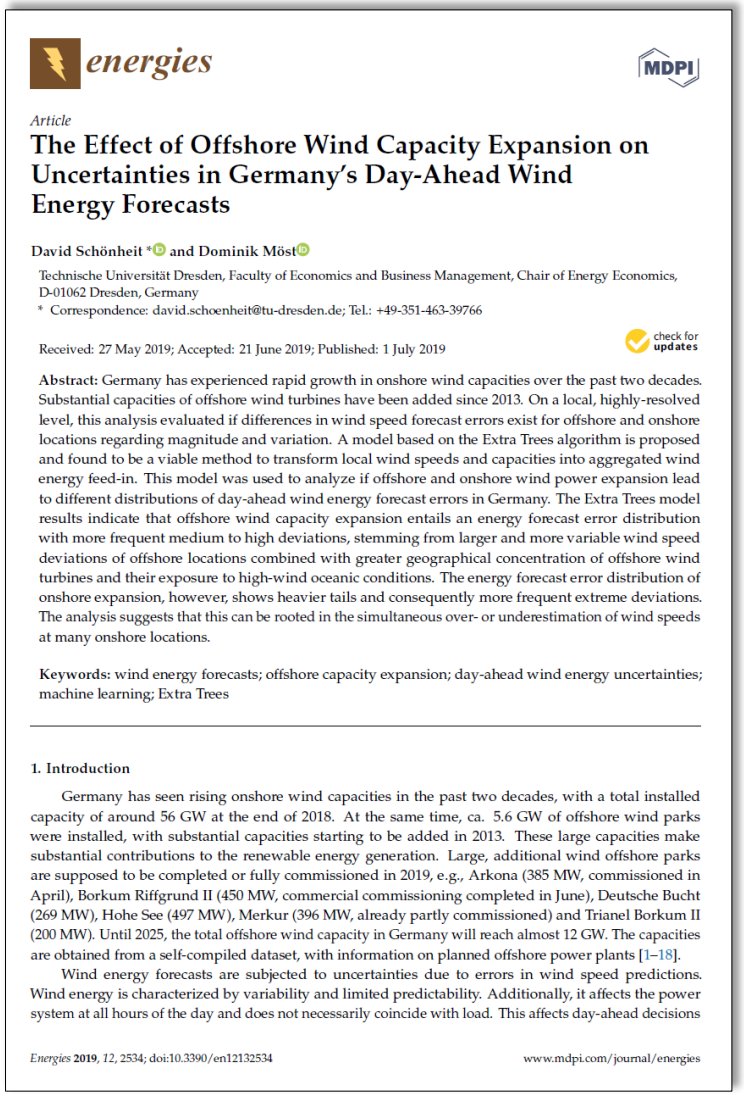
Results: Categorical shares of absolute wind energy forecast errors for the three analyzed cases



Conclusion

- Wind capacity expansion leads to greater absolute deviations
  - Fewer deviations < 1 GW
  - More deviations 1 - 5 GW
- Offshore wind capacity expansion leads to more frequent deviations from 0.5 - 5 GW than onshore expansion
- Onshore wind capacity expansion leads to more frequent deviations ≥ 5 GW
  - Near-shore locations with large forecast errors
  - Simultaneous over- or under-estimations of many onshore locations (higher spatial correlation)

Open access publication addressing the research question



energies

MDPI

Article

The Effect of Offshore Wind Capacity Expansion on Uncertainties in Germany's Day-Ahead Wind Energy Forecasts

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Abstract: Germany has experienced rapid growth in onshore wind capacities over the past two decades. Substantial capacities of offshore wind turbines have been added since 2013. On a local, highly-resolved level, this analysis evaluated if differences in wind speed forecast errors exist for offshore and onshore locations regarding magnitude and variation. A model based on the Extra Trees algorithm is proposed and found to be a viable method to transform local wind speeds and capacities into aggregated wind energy feed-in. This model was used to analyze if offshore and onshore wind power expansion lead to different distributions of day-ahead wind energy forecast errors in Germany. The Extra Trees model results indicate that offshore wind capacity expansion entails an energy forecast error distribution with more frequent medium to high deviations, stemming from larger and more variable wind speed deviations of offshore locations combined with greater geographical concentration of offshore wind turbines and their exposure to high-wind oceanic conditions. The energy forecast error distribution of onshore expansion, however, shows heavier tails and consequently more frequent extreme deviations. The analysis suggests that this can be rooted in the simultaneous over- or underestimation of wind speeds at many onshore locations.

Keywords: wind energy forecasts; offshore capacity expansion; day-ahead wind energy uncertainties; machine learning; Extra Trees

1. Introduction

Germany has seen rising onshore wind capacities in the past two decades, with a total installed capacity of around 56 GW at the end of 2018. At the same time, ca. 5.6 GW of offshore wind parks were installed, with substantial capacities starting to be added in 2013. These large capacities make substantial contributions to the renewable energy generation. Large, additional wind offshore parks are supposed to be completed or fully commissioned in 2019, e.g., Arkona (385 MW, commissioned in April), Borkum Riffgrund II (450 MW, commercial commissioning completed in June), Deutsche Bucht (269 MW), Hohe See (497 MW), Merkur (396 MW, already partly commissioned) and Trianel Borkum II (200 MW). Until 2025, the total offshore wind capacity in Germany will reach almost 12 GW. The capacities are obtained from a self-compiled dataset, with information on planned offshore power plants [1–18].

Wind energy forecasts are subjected to uncertainties due to errors in wind speed predictions. Wind energy is characterized by variability and limited predictability. Additionally, it affects the power system at all hours of the day and does not necessarily coincide with load. This affects day-ahead decisions

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Questions?

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