A novel approach to generate bias-corrected regional wind infeed timeseries based on reanalysis data

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Open-Minded

Motivation

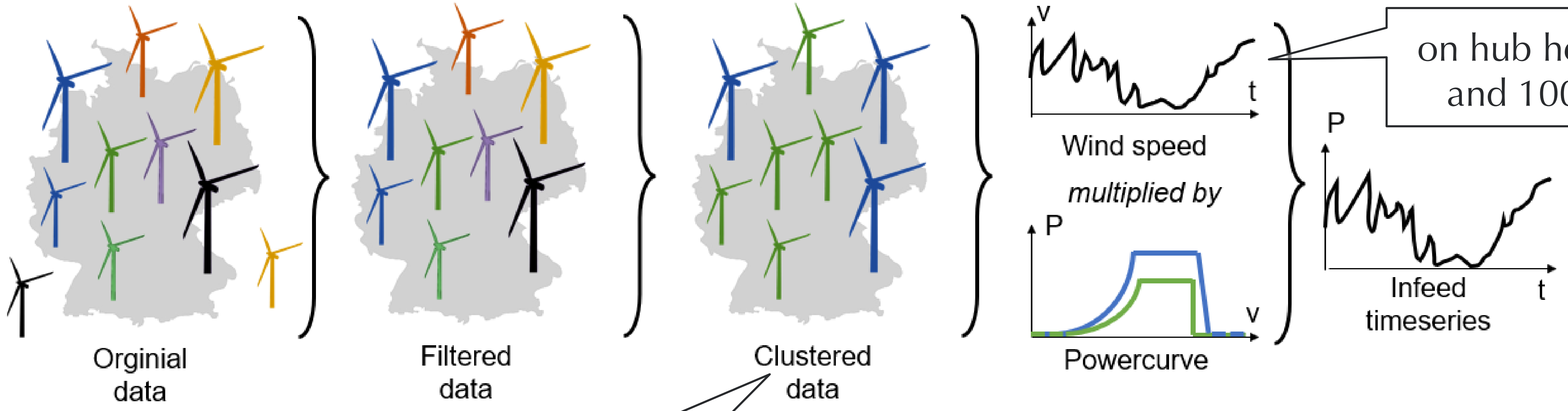
- Power system modeling and scenario generation needs accurate models dealing with realistic wind speeds
- Generation of wind power supply timeseries is strongly affected by **data availability**
  - Wind speed measurements on hub height barely/not publicly accessible
  - Weather station measurement data are not representative for different landscapes

→ (imperfect) **Reanalysis weather models** are often used

- Create long-term weather data using numerical weather prediction models and assimilating historical data
- Consistent dataset of atmospheric parameters in spatial and temporal resolution
- Limited representation of local topography

- Reduction of erroneous wind speed simulation with **local** bias correction
  - So far only based on spatially aggregated information
  - now on turbine level

Bottom-up simulation on wind power using reanalysis data



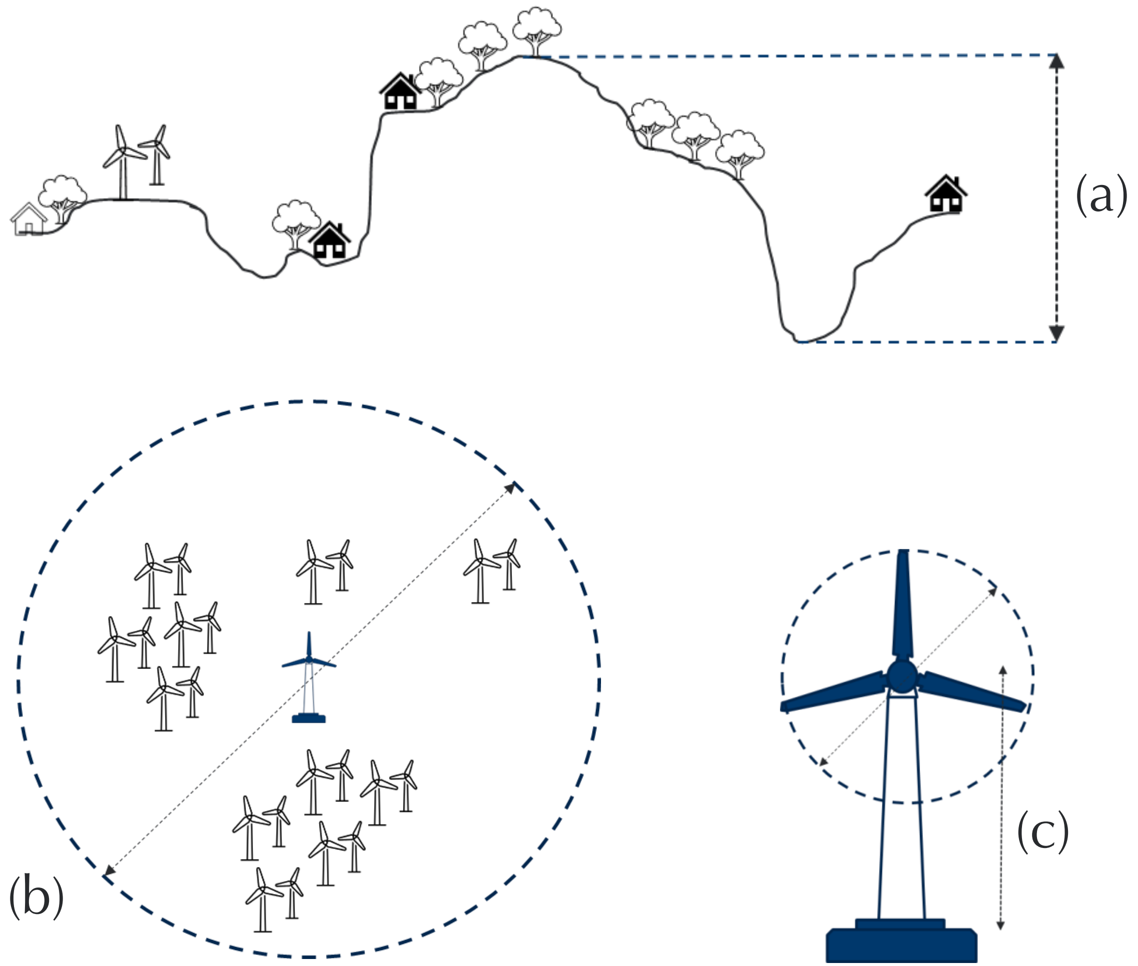
on hub height based on 10 and 100m wind speeds

8 turbine types according to net power rating, hub height and rotor diameter

- $P_j(t) = \frac{P_k^{powercurve}(v_{hh}(t))}{\max\{P_k^{powercurve}\}} \cdot P_j^{netPower} \cdot \eta \quad \forall t \in \mathcal{T}$
  - η: assumed factor for technical unavailability
- $P_j^{simulated}(t) = P_j(t) - P_j^{curtailment}(t)$
  - Curtailment in case the electrical grid cannot handle the high amount of wind infeed

Local factors

- Identification of relevant local aspects that cause a deviation between measured wind infeed and simulated data. Factors indicate spatial characteristics to some degree.
  - Height above sea level
  - Hilliness of the surroundings (a)
  - Distance to sea
  - Amount of turbines nearby (b)
  - Turbine specifications (hub height, rotor diameter, net power rating) (c)



Bias correction for full load hours

Calculate (yearly) **deviation in full load hours** for every turbine

$$\Delta FLH_j = \frac{prod_j^{simulated} - prod_j^{TSO}}{P_j^{netPower}}$$

→

Multiple linear regression

→ estimates β_0 and β

→

Estimate offset in full load hours between simulated and measured data in target year using β of the base year

$$\widehat{\Delta FLH}_{base,target} = \beta_0 + \beta \mathbf{x}$$
$$\mathbf{x} = [x_1 \; x_2 \; x_3 \dots x_n]^T$$

→

Local **bias-corrected simulated production**: sum of simulated time series corrected by full load hour offset

$$prod_{base,target} = \sum_{t=1}^{8760} P_j^{simulated}(t) - \widehat{\Delta FLH}_{base,target} \cdot P^{netPower}$$

- Verification of the results by comparing
  - $\Delta FLH^{simulated}$: deviations in FLH in the simulated (uncorrected) model
  - $\Delta FLH_{base,target}$: deviations in the bias-corrected model.

Data

Wind speed on 10 and 100m in 0.25°x0.25° grid	ERA 5 Reanalysis (Copernicus, Europe's eyes on Earth; implemented by ECMWF; Climate Change Service)
Turbine Data	Bundesnetzagentur; MaStR Marktstammdatenregister
Power curves	The WindPower – Wind Energy Market Intelligence
Local properties	eurostat; GISCO: GEOGRAPHICAL INFORMATION AND MAPS; Bundesamt für Kartographie und Geodäsie; WMS Digitales Geländemodell Gitterweite 200 m
Energy production	NETZTRANSPARENZ.DE – Informationsplattform der deutschen Übertragungsnetzbetreiber; EEG-Jahresabrechnungen
Curtailment	avacon; e.dis; Schleswig-Holstein Netz

- Extensive dataset of
  - 22,969 turbines in 2016 (BNetzA: 26,057)
  - 25,430 turbines in 2020 (BNetzA: 28,579)
  - 26,018 turbines in 2021 (BNetzA: 28,818)

Regression estimates

Regression estimates for 2016, 2020 and 2021

	2016 ERA5			2020 ERA5			2021 ERA5		
	Estimate	tStat		Estimate	tStat		Estimate	tStat	
Intercept (β_0)	789.977	12.726	***	886.817	14.265	***	786.948	14.689	***
Height above sea	0.792	7.009	***	0.446	4.503	***	0.565	6.890	***
Hilliness of the surroundings	-75.938	-5.115	***	-37.051	-2.866	**	-44.673	-3.953	***
Distance to sea	-1.692	-14.339	***	-1.536	-14.355	***	-1.414	-15.891	***
Amount of turbines around	0.691	2.173	**	1.010	3.673	***	1.137	4.586	***
Hub height	-1.347	-3.048	**	-1.714	-4.328	***	-2.007	-5.750	***
Rotor diameter	-1.674	-1.699		-2.907	-3.790	***	-2.212	-3.419	***
Net power rating	0.104	4.727	**	0.102	5.359	***	0.094	5.538	***
R^2	0.271			0.251			0.271		
RMSE	348			372			321		

* p<0.05, ** p<0.01, *** p<0.001

- R^2, RMSE and parameter estimates of all models lie in the same order of magnitude
- All parameters are significant, except the rotor diameter of 2016

e.g.: the further we move away from the sea, the less is corrected

Step-forward prediction

Bias-correction from base to simulation year

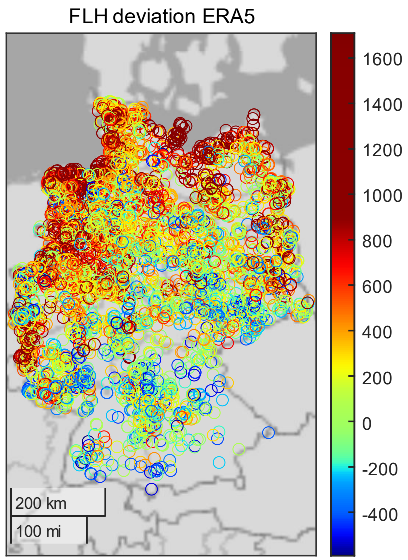
Base year	**2016**	**2016**	**2020**
Target year	**2020**	**2021**	**2021**
Measured production $\mathbf{prod}^{\mathbf{TSO}}$ [TWh]	82.670	75.480	75.480
Simulated production $\mathbf{prod}^{\mathbf{simulated}}$ [TWh]	98.460	87.880	87.880
Corrected production $\mathbf{prod}_{\mathbf{base,target}}$ [TWh]	87.200	76.330	71.750
Full load hour deviation $\mathbf{\Delta FLH}_{\mathbf{base,target}}$ [h]	101.010	18.178	-79.771
$\varepsilon^{simulated} = (prod^{simulated} - prod^{TSO}) / prod^{TSO}$	0.191	0.164	0.164
$\varepsilon_{base,target} = (prod_{base,target} - prod^{TSO}) / prod^{TSO}$	0.055	0.011	-0.049
$\varepsilon_{impr} = (\lvert\varepsilon^{simulated}\rvert - \lvert\varepsilon_{base,target}\rvert) / \lvert\varepsilon^{simulated}\rvert$	0.713	0.931	0.699

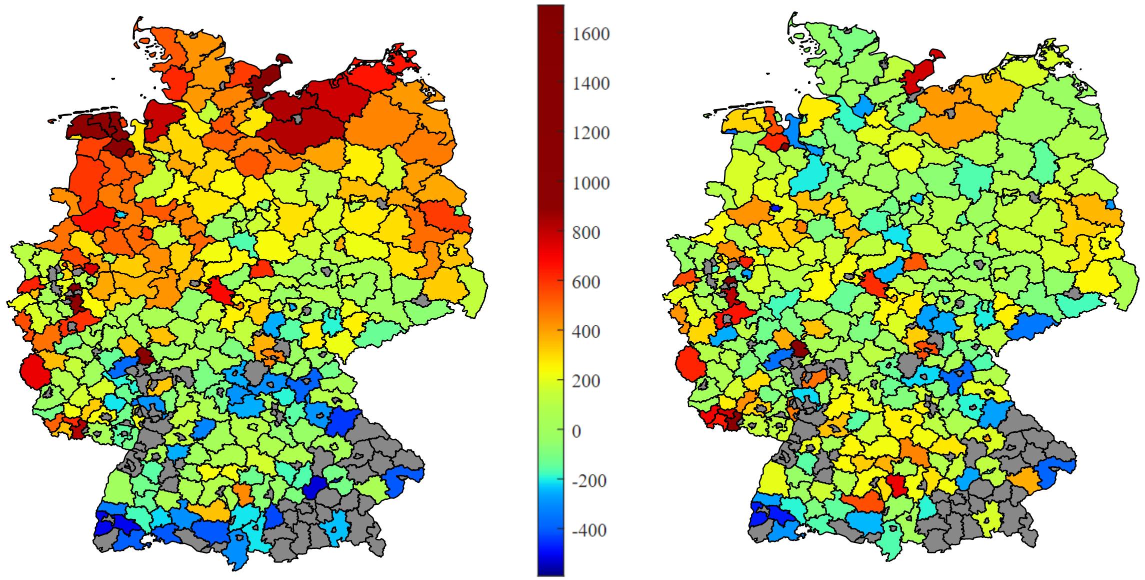
- With base year regression estimates, the deviation in the target year can be estimated for each turbine. The simulated infeed is corrected by this estimated deviation.

- In all cases, an application of bias-correction based on local indicators reduces the error of the reanalysis-based output simulation
  - Regression estimates from 2016 lead to an error reduction of 71.3 % (2020) and 93.1 % (2021)
  - Regression estimates from 2020 lead to an error reduction of 69.9 % (2021)

Site-specific and regional results

- Compare deviation of full load hours between simulated (left side) and bias-corrected (right side) model with TSO information. Here: 2020 with estimates of 2016
- Red color indicates an overestimation, blue color an underestimation of the model





- Site-specific
  - Number of large overestimations reduced
  - Unsystematic pattern after local bias correction → no structural bias after applying the model
- Regional (NUTS 3)
  - Great improvements in northern regions with many installed turbines
  - Good improvements in most regions of central Germany
  - Some southern regions: model increases deviation (but regions have low output)

Final remarks

- Our model **improves bottom-up simulated data** for energy system modelling and **depicts infra-national differences** and local distortions better than previous bias-correction methods
- We obtain promising results for different combinations of base and target years: factors can be **applied for other target years** given that geographical and technical circumstances remain sufficiently the same.
- The multilinear regression is a suitable abstraction from complex physical flows and can be applied as **good bias-correction without extensive modelling of the aerodynamics** in the boundary layer of the atmosphere.
- Limitations:
  - Simulated timeseries are based on reference turbine properties.
  - Several shut-off events of turbines are not modelled (regulatory, network-based, market-based, animal protection,…).
  - Study focuses on Germany. Transferability to other climate regions requires further research.

References (I/II)

Holttinen, H. Wind Integration: Experience, Issues and Challenges. [Buchverf.] Peter Lund, et al. *Advances in Energy Systems: The Large-scale Renewable Energy Integration Challenge*. 2019.

Davidson, M. und Millstein, D. Limitations of reanalysis data for wind power applications. *Wind Energy*. 25, 2022, Bd. 9.

ENTSO-E. Mid-term adequacy Forecast Appendix 2. *Methodology*. [Online] 2019. [Zitat vom: 22. 11 2022.] https://eepublicdownloads.entsoe.eu/clean-documents/sdc-documents/MAF/2019/MAF-2019-Appendix_2-Methodology.pdf.

Ren, Guorui, et al. Overview of wind power intermittency: Impacts, measurements, and mitigation solutions. *Applied Energy*. 204, 2017.

Emeis, Stefan. Current issues in wind energy meteorology. *Meterological Applications*. 2014.

Olauson, Jon. ERA5: The new champion of wind power modelling? *Renewable Energy*. 126, 2018.

Petersen, Erik, et al. Wind Power Meteorology. Part II:Siting and Models. *Wind Energy*. 1, 1998.

Gruber, Katharina, et al. Towards global validation of wind power simulations: A multi-country assessment of wind power simulation of MERRA-2 and ERA-5 reanalyses bias-corrected with the global wind atlas. *Energy*. 238, 2022.

Gupta, S und Nema, R. A Critical Review on Wind Turbine Power Curve Modelling Techniques and Their Applications in Wind Based Energy Systems. *Journal of Energy*. 2016.

Kaspar, Frank, et al. Regional atmospheric reanalysis activities at Deutscher Wetterdienst: review of evaluation results and application examples with a focus on renewable energy. *Adv. Sci. Res*. 2020.

Hersbach, Hans, et al. The ERA5 global reanalysis. *Copernicus Climate Change Service, Climate Data Store*. [Online] [Zitat vom: 1. 10 2022.] cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-era5-single-levels?tab=overview.

Rao, Kamisetty. *Wind Energy for Power Generation*. Cham : Springer, 2019.

Brune, Sebastian, Keller, Jan D. und Wahl, Sabrina. Evaluation of wind speed estimates in reanalyses for wind energy applications. *Advances in Science and Research*. 2021, 18, S. 115–126.

Murcia, Juan, et al. Validation of European-scale simulated wind speed and wind generation time series. *Applied Energy*. 305, 2022.

Jourdier, Bénédicte. Evaluation of ERA5, MERRA-2, COSMO-REA6, NEWA and AROME to simulate wind power production over France. *Adv. Sci. Res. (Advances in Science and Research)*. 17, 2020.

References (II/II)

Pöstges, Arne und Weber, Christoph. *Identifying key elements for adequate simplifactions of investment choices -- the case of wind energy expansion.* s.l. : HEMF Working Paper No. 01/2021, 2021.

Browner, Michael. *Wind Resource Assessment: A Practical Guide to Developing a Wind Project.* s.l. : John Wiley & Sons, Inc. , 2012.

White, Halbert. A heteroskedasticiy-consistent convariance matrix estimator and a direct test for heteroskedasticity. *Economietrica.* 48, 1980.

Bundesnetzagentur. *Marktstammdatenregister.* [Online] [Zitat vom: 1. 10 2022.] https://www.marktstammdatenregister.de/MaStR/.

The Wind Power. Databases and Reports. [Online] [Zitat vom: 1. 10 202.] www.thewindpower.net.

eurostat. GISCO: Geographical Information and maps. [Online] https://ec.europa.eu/eurostat/en/web/gisco/geodata/reference-data/administrative-units-statistical-units/nuts.

Bundesamt für Kartographie und Geodäsie. WMS Digitales Geländemodell Gitterweite 200 m (wms_dgm200). [Online] 2019. https://gdz.bkg.bund.de/index.php/default/wms-digitales-gelandemodell-gitterweite-200-m-wms-dgm200.html.

Netztransparenz.de. Informationsplattform der deutschen Übertragungsnetzbetreiber. [Online] [Zitat vom: 1. 10 2022.] www.netztransparenz.de.

Avacon. Einspeisemanagement - Abgeschlossene Maßnahmen. [Online] [Zitat vom: 1. 10 2022.] https://www.avacon-netz.de/de/energie-einspeisen/einspeisemanagement/veroeffentlichungen/abgeschlossene-massnahmen.html#.

E.dis-Netz. Einspeisemanagement - Abgeschlossene Maßnahmen. [Online] [Zitat vom: 1. 10 2022.] https://www.e-dis-netz.de/de/energie-einspeisen/einspeisemanagement/veroeffentlichungen/abgeschlossene-massnahmen.html.

Sh-Netze. Einspeisemanagement - Abgeschlossene Maßnahmen. [Online] [Zitat vom: 1. 10 2022.] https://www.sh-netz.com/de/energie-einspeisen/einspeisemanagement/veroeffentlichungen/abgeschlossene-massnahmen.html.

Bundesnetzagentur, Bundeskartellamt. *Monitoringbericht 2022.* 2022.

ENTSO-E. Transparency Platform, Actual Generation per Production Type. [Online] 2021. [Zitat vom: 3. 11 2022.] https://transparency.entsoe.eu/.

Jung, Christopher und Schindler, Dirk. The role of the power law exponent in wind energy assessment: A global analysis. *Interantional Journal of Energy Research.* 45, 2021, 6.

—. On the inter-annual variability of wind energy generation – A case study from Germany. *Applied Energy.* 230, 2018.

Deutscher Wetterdienst. COSMO Regional Reanalysis. [Online] [Zitat vom: 1. 10 2022.] https://reanalysis.meteo.uni-bonn.de/?COSMO-REA6.

European Union, Copernicus Land Monitoring Service. s.l. : European Union, Copernicus Land Monitoring Service 2018, European Environment Agency (EEA), 1. 10 2022.

Thank you for your attention!

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