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The Intersection of Climate and Renewable Energy Research: Successes and Limitations

Andrea N. Hahmann, Graziela Luzia and Matti Koivisto
Technical University of Denmark, Dept of Wind and Energy Systems

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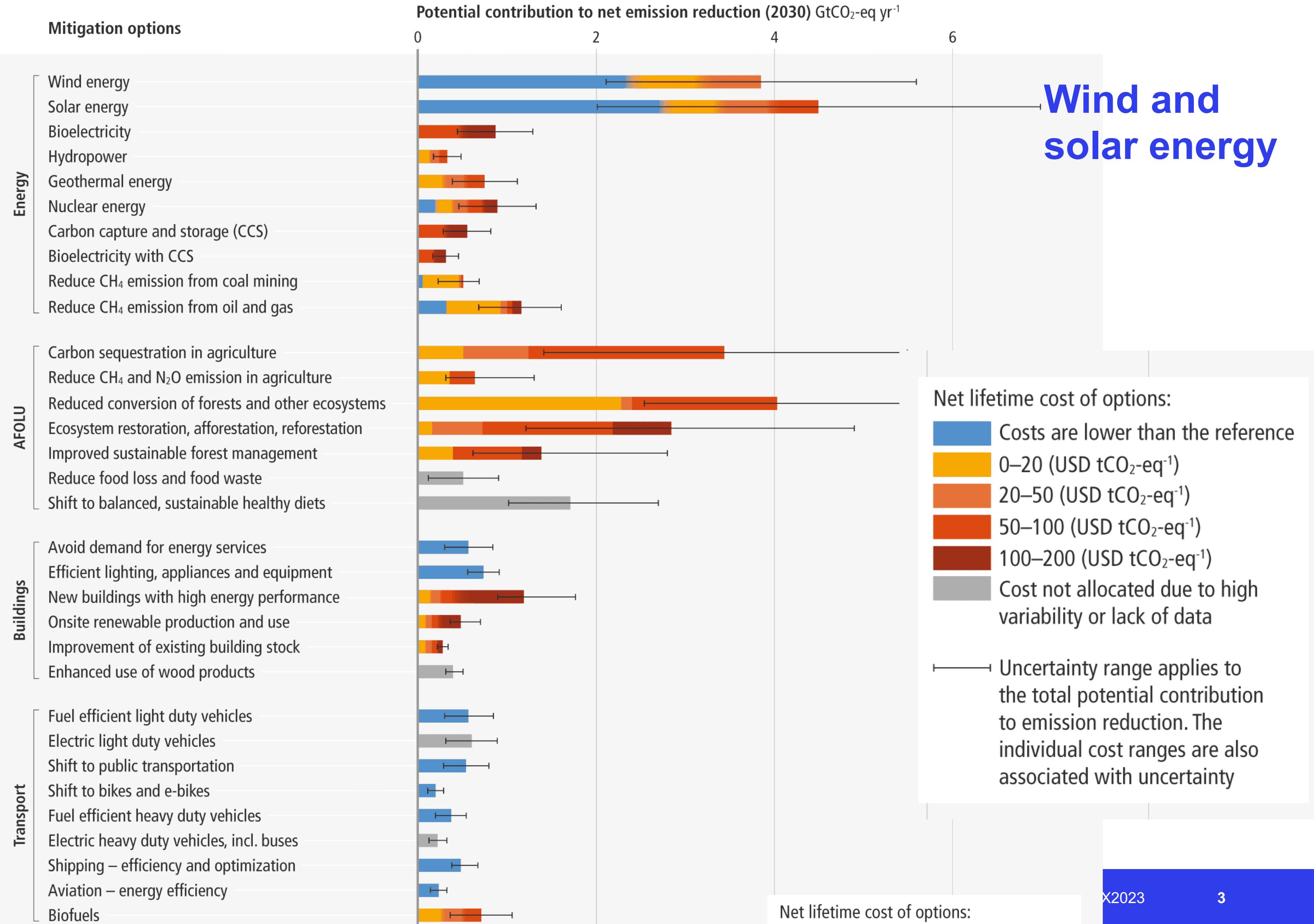
SIXTH ASSESSMENT REPORT
Working Group III – Mitigation of Climate Change
ipcc INTERGOVERNMENTAL PANEL ON climate change
WMO UNEP

Motivation

- Harvesting electricity from renewable energy sources is vital in climate change mitigation.
- However, **climate change may influence the conditions in which wind turbines and PV panels** operate and the resources they are designed to harness.
- **Does climate research provide the data so far able to answer these questions?**

Many options available now in all sectors are estimated to offer substantial potential to reduce net emissions by 2030. Relative potentials and costs will vary across countries and in the longer term compared to 2030.



Wind and solar energy

What aspects of the simulated wind climate need to be accurately simulated?

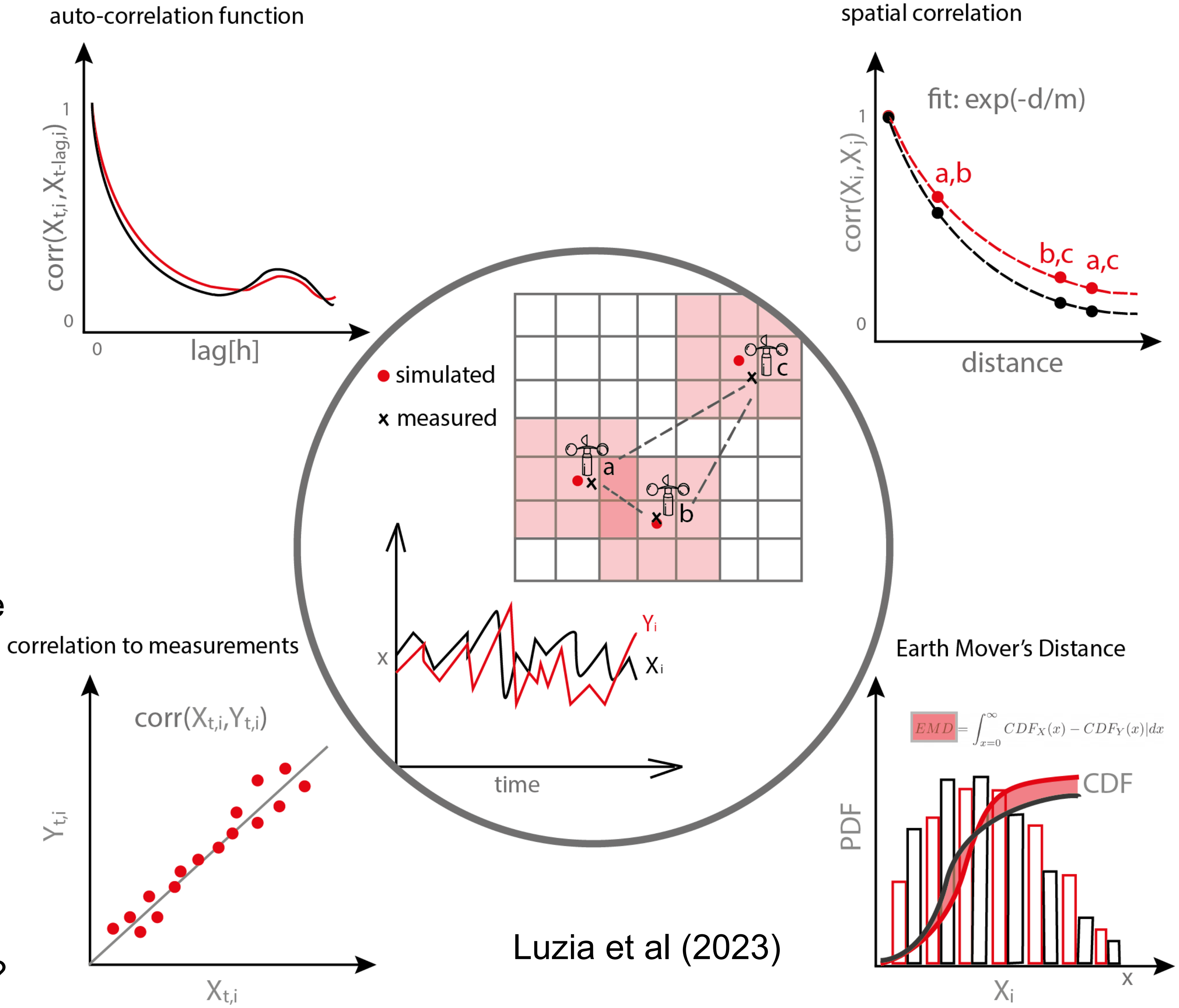
The metrics needed to simulate the power system accurately <u>depend on the application</u> [Sorry. Models are imperfect! 😁]

Wind speed and direction distributions ➡ How much energy can a wind farm will produce?

Long-term averages and trends ➡ Would there be enough resources in the future?

Temporal correlations and auto-correlations ➡ How to design the power system to accommodate weather variability.

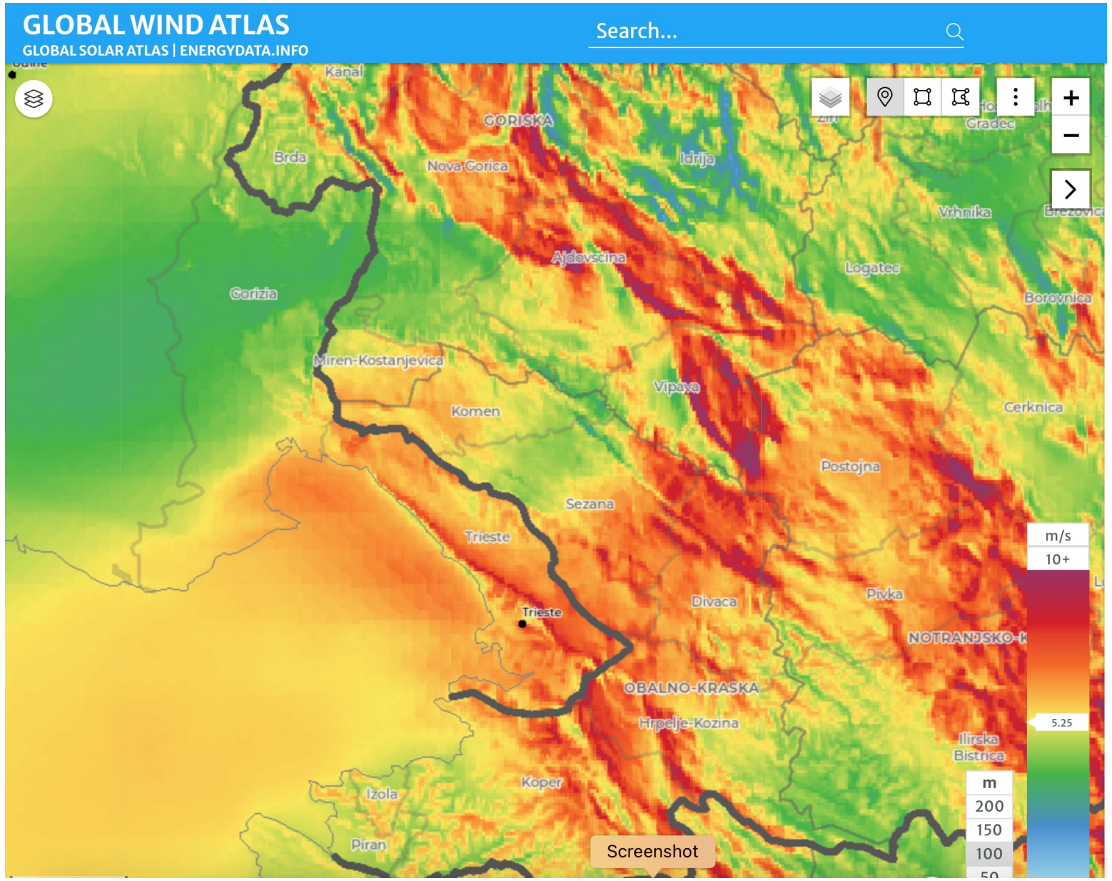
Spatial/temporal correlations ➡ Is there enough wind and solar energy to drive the energy system?



Luzia et al (2023)

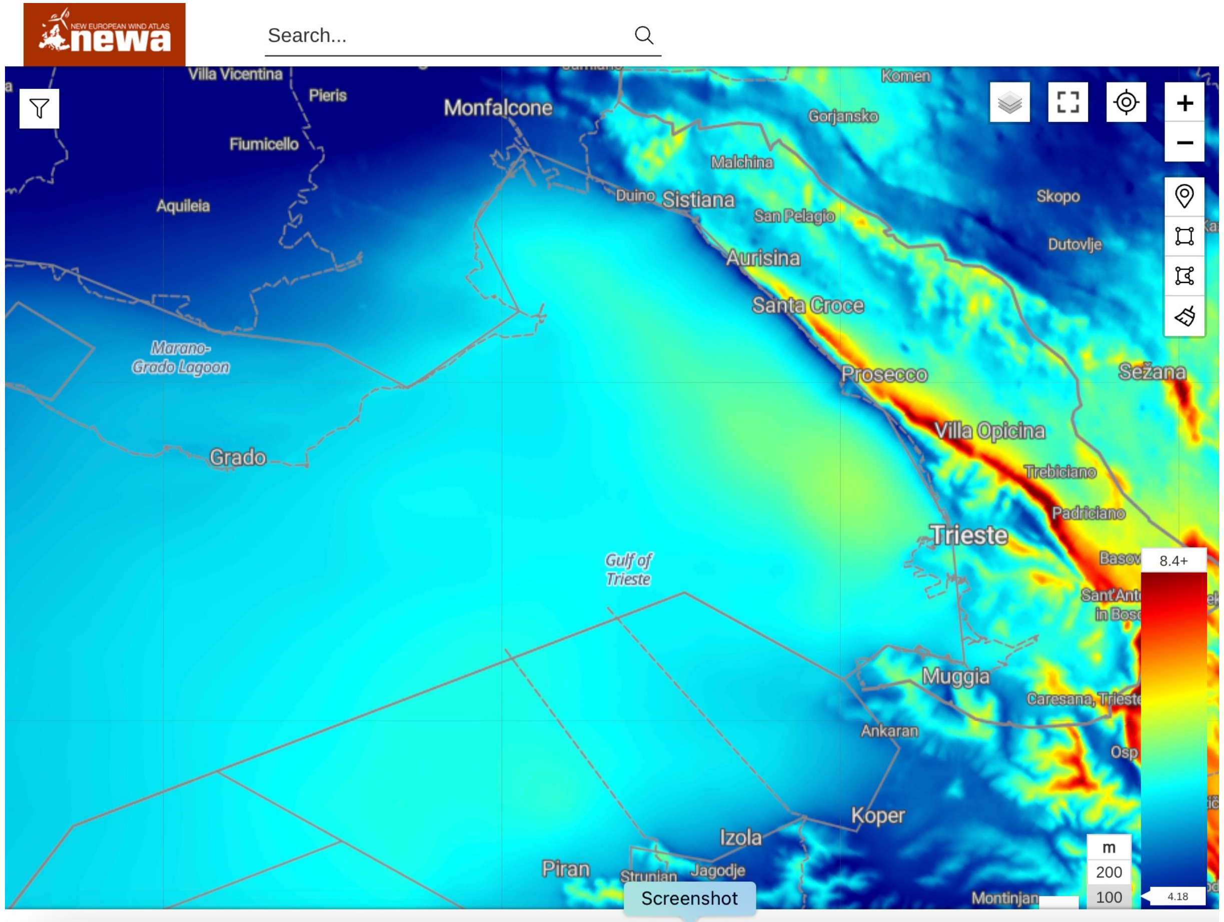
The wind resources for <u>the past</u> (10-30 years)

Dynamical downscaling
ERA5 forcing (27 km)
WRF downscaling (3 km)
Wind resources WAsP flow model 250 m GWA, 50 m NEWA



The Global Wind Atlas

https://globalwindatlas.info/en



The New European Wind Atlas

https://map.neweuropeanwindatlas.eu/

ERA5, NEWA Validation against 291 tall masts in Europe

ERA5 too low at **complex sites**

microscale (WAsP) too high due to linearized model

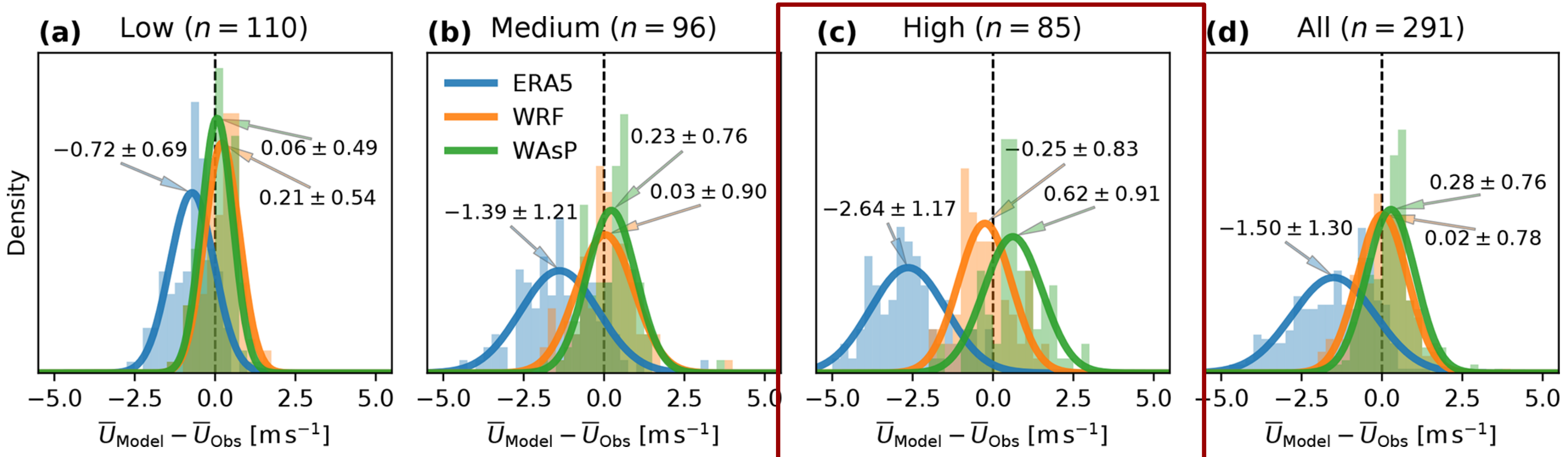


Figure 9. Distributions of wind speed biases ($\overline{U}_{Model} - \overline{U}_{Obs}$) for ERA5, WRF, and WAsP split by ruggedness index (RIX) category: low **(a)**, medium **(b)**, high **(c)**, and all of the samples combined **(d)**. Fitted normal distributions (lines) are annotated by the mean and standard deviation of the samples ($\mu \pm \sigma$). The number of masts (n) in each category is indicated above the subplots.

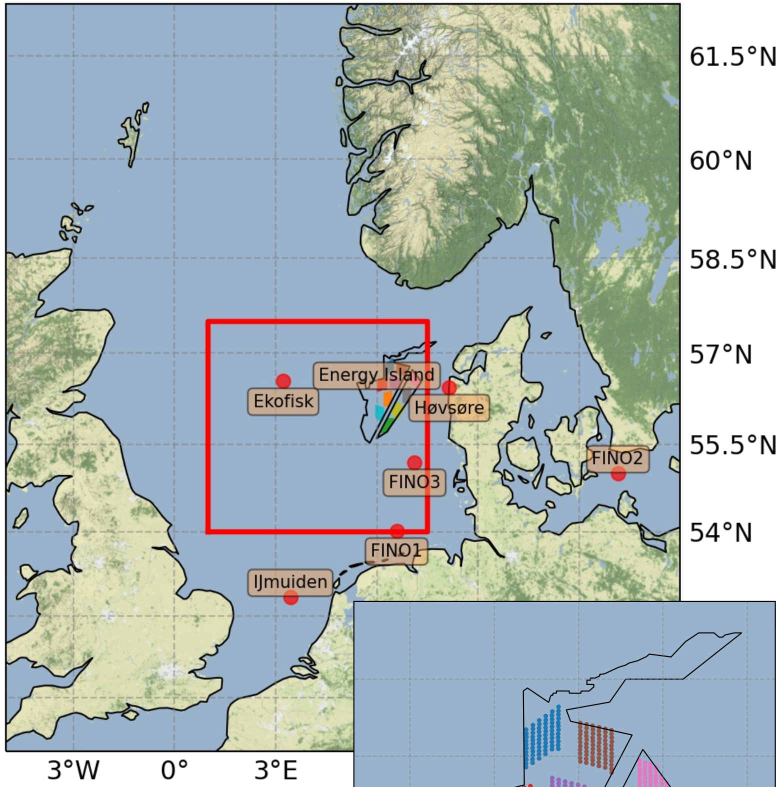
NEWA, Dörenkämper et al (2020)
https://doi.org/10.5194/gmd-13-5079-2020

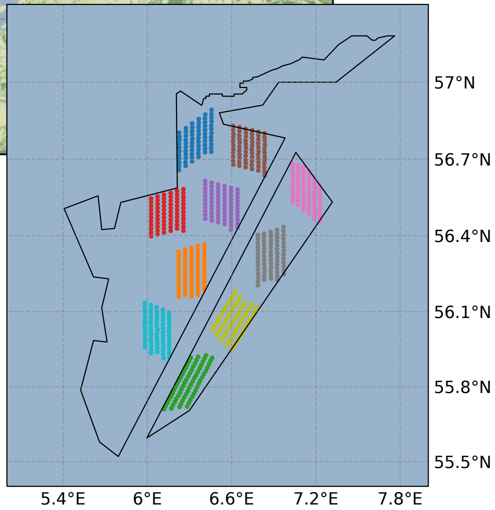
Energy production for the planned North Sea Energy Island

10 wind farms x 67 turbines x 15 MW reference wind turbine (NREL)

Jensen engineering **wake model**

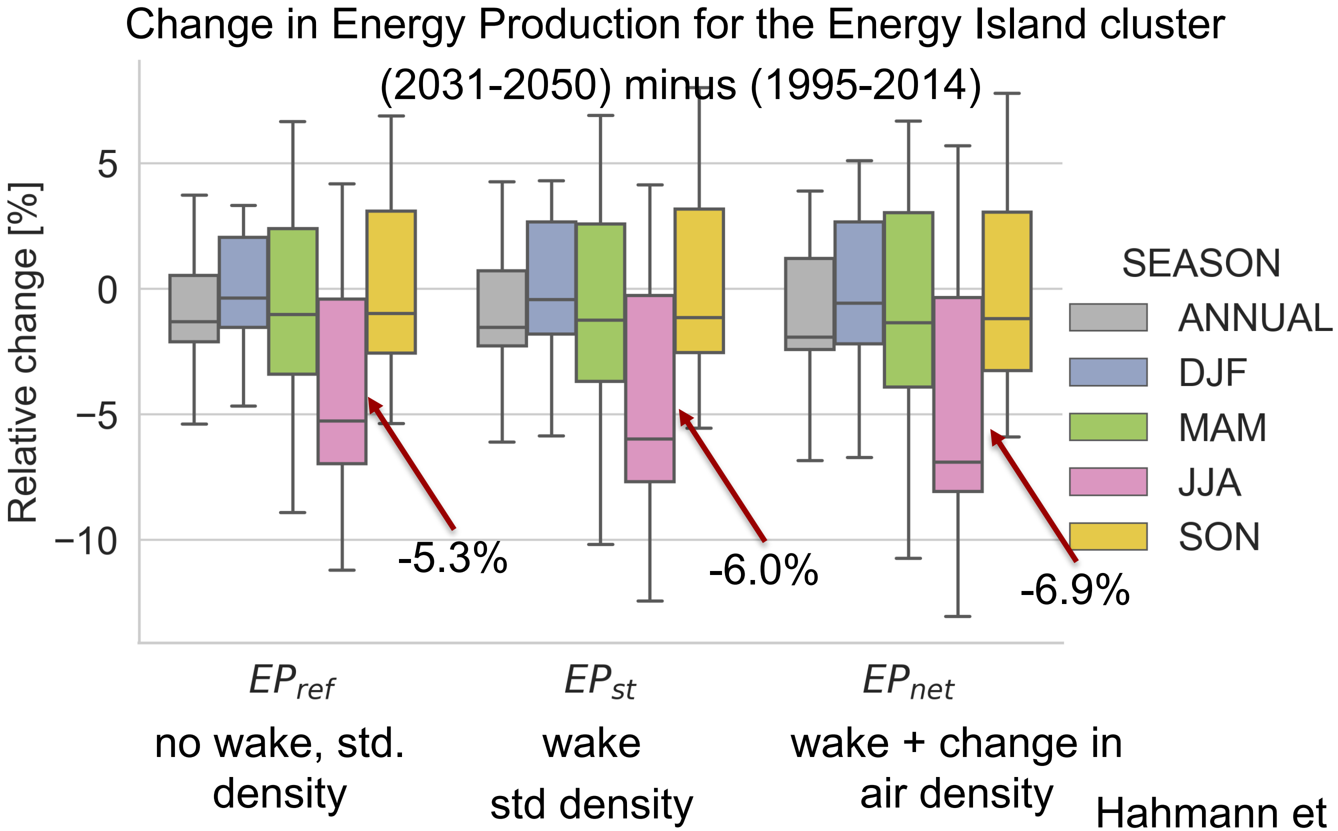
Wind speed and direction from 16 CMIP6 models (AEP within 10% of the value calculated by using ERA5), wind time series at 150 m AMSL





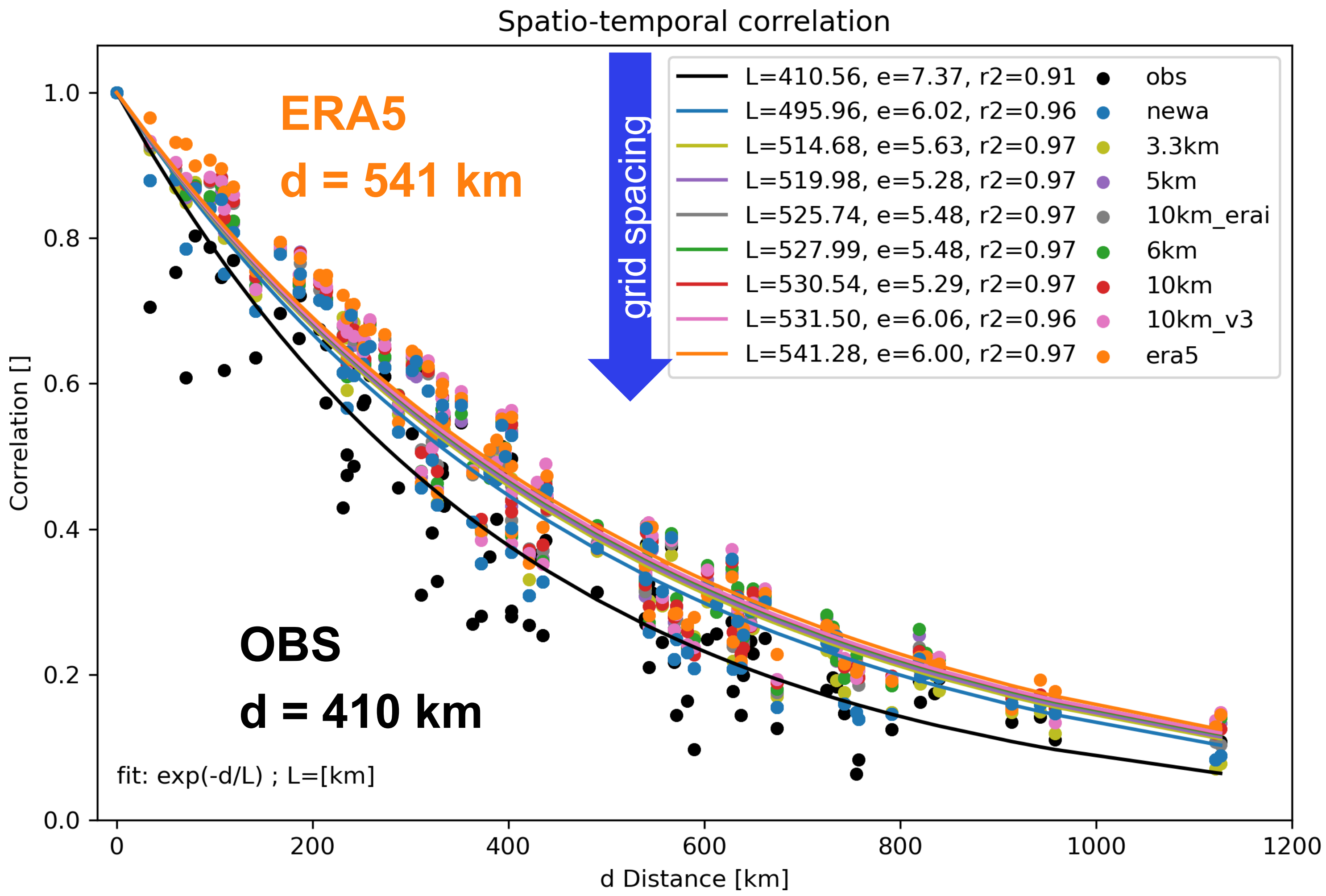
Future Energy Island wind farm cluster

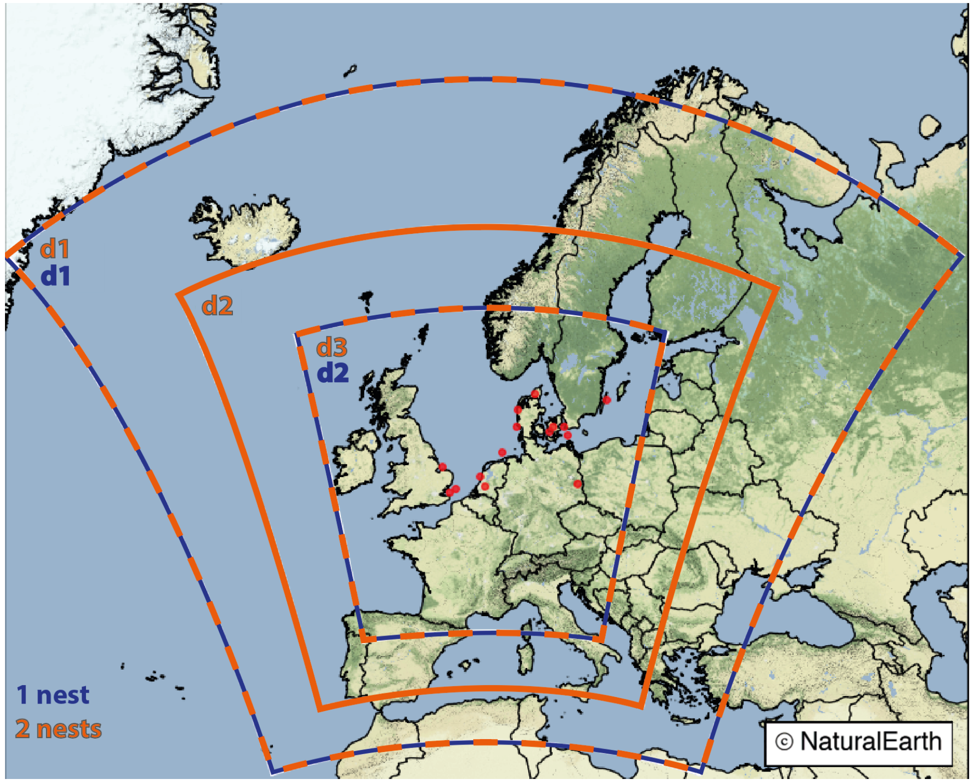
10 GW by 2050



Hahmann et al (2022)

Spatial correlations, the effect of model resolution





Correlation between pairs of wind speed points (hourly data), Observations and models

Plotted here as a function of the distance between the points

Luzia et al (2022)

Validation of Euro-CORDEX simulations against wind power generation

Table 1
Details of the EURO-CORDEX climate simulations. Heights are the number of heights above ground level: a combination of near-surface (10 m) with either one (100 m) or five (50, 100, 150, 200 and 250 m) fixed levels of wind speed, according to the ESGF availability for each model. For models with more than one available scenario, the bold RCP name indicates the representative model used in the validation.

Forcing GCM/ESM	RCM	Short name	Experiments	Heights	References
CNRM-CERFACS-CNRM-CM5[a]	ALADIN63[b]	CNRM_A	**RCP2.6**, RCP8.5	6 levels	[a] [41], [b] [42],
MOHC-HadGEM2-ES[c]	ALADIN63	MOHC_A	RCP8.5	6 levels	[c] [43]
NCC-NorESM1-M[d]	ALADIN63	NCC_A	RCP8.5	6 levels	[d] [44]
CNRM-CERFACS-CNRM-CM5	RegCM4-6[e]	CNRM_R	RCP8.5	2 levels	[e] [45]
ICHEC-EC-EARTH[f]	RegCM4–6	ICHEC_R	RCP8.5	2 levels	[f] [46]
MPI-M-MPI-ESM-LR[g]	RegCM4–6	MPI_R	**RCP2.6**, RCP8.5	2 levels	[g] [47]
NCC-NorESM1-M	RegCM4–6	NCC_R	**RCP2.6**, RCP8.5	2 levels	

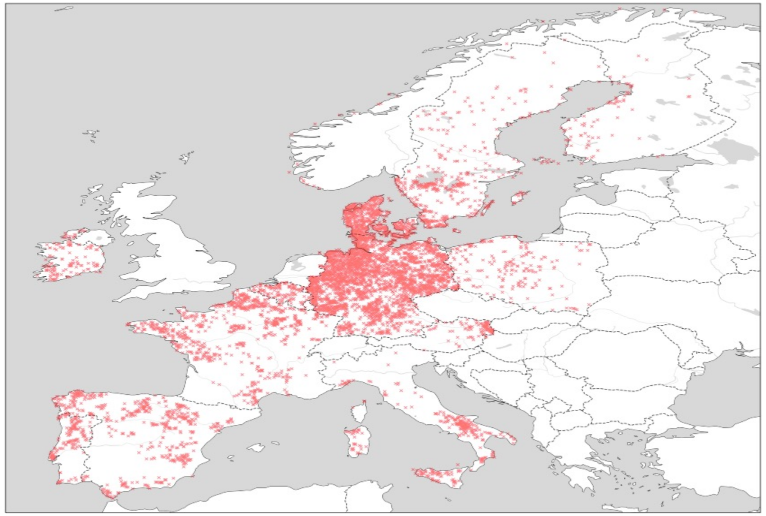
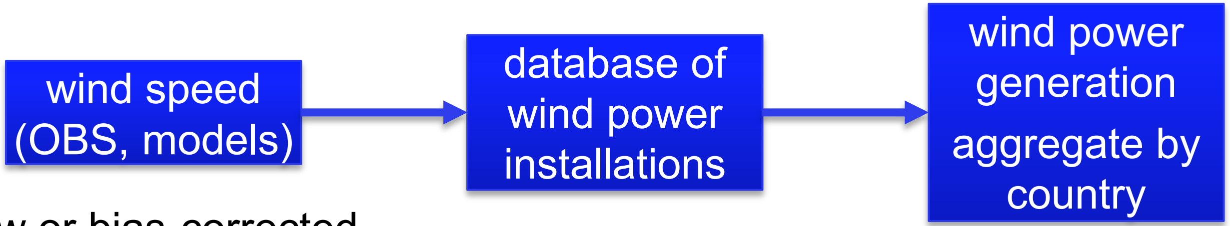


Fig. 2. Location of wind power plants operating in 2018.



raw or bias-corrected
at turbine height

Luzia et al (2023)

Capacity factor = Energy Produced/Energy produced at full operation

Capacity factor error [ ]

	Austria	Germany	Denmark	Spain	Finland	France	Ireland	Italy	Norway	Poland	Portugal	Sweden	mean	std
gERA5	-0.01	0.02	0.01	0.02	-0.07	-0.04	0.00	-0.02	-0.02	0.02	0.05	0.04	0.00	0.03
gCNRM_A	-0.00	0.02	0.00	0.03	-0.07	-0.03	-0.00	-0.01	-0.01	0.02	0.07	0.04	0.00	0.04
gMOHC_A	-0.00	0.02	0.01	0.03	-0.07	-0.04	-0.00	-0.01	-0.01	0.02	0.07	0.04	0.00	0.04
gNCC_A	-0.01	0.02	0.01	0.02	-0.06	-0.04	-0.00	-0.02	-0.00	0.02	0.06	0.05	0.00	0.03
gCNRM_R	-0.00	0.02	0.00	0.03	-0.06	-0.03	0.00	-0.01	-0.01	0.02	0.07	0.04	0.00	0.03
gICHEC_R	0.00	0.02	0.01	0.03	-0.07	-0.03	0.00	-0.00	-0.02	0.02	0.07	0.04	0.01	0.04
gMPI_R	0.00	0.02	0.01	0.03	-0.07	-0.03	0.00	-0.01	-0.01	0.02	0.07	0.04	0.00	0.03
gNCC_R	-0.00	0.02	0.00	0.03	-0.07	-0.04	0.00	-0.01	-0.02	0.01	0.07	0.04	0.00	0.04
ERA5	0.06	0.06	-0.07	0.10	-0.02	0.01	0.07	0.11	0.02	0.01	0.16	0.05	0.05	0.06
CNRM_A	-0.00	0.02	-0.05	0.03	-0.07	-0.03	0.07	0.03	0.07	-0.03	0.12	0.07	0.02	0.06
MOHC_A	0.00	-0.01	-0.11	0.05	-0.11	-0.04	0.04	0.05	0.02	-0.06	0.14	0.02	-0.00	0.07
NCC_A	0.01	-0.01	-0.10	0.06	-0.08	-0.04	0.05	0.05	0.05	-0.05	0.15	0.04	0.01	0.07
CNRM_R	0.01	0.02	-0.08	-0.05	-0.04	-0.04	0.03	-0.07	-0.08	0.01	0.03	0.05	-0.02	0.05
ICHEC_R	0.02	0.01	-0.10	-0.03	-0.08	-0.04	0.00	-0.05	-0.12	0.00	0.05	0.02	-0.03	0.05
MPI_R	0.00	0.02	-0.09	-0.08	-0.07	-0.06	0.01	-0.07	-0.10	0.00	0.01	0.03	-0.03	0.05
NCC_R	0.02	0.00	-0.11	-0.02	-0.06	-0.05	0.01	-0.05	-0.10	-0.01	0.06	0.03	-0.02	0.05

Bias corrected

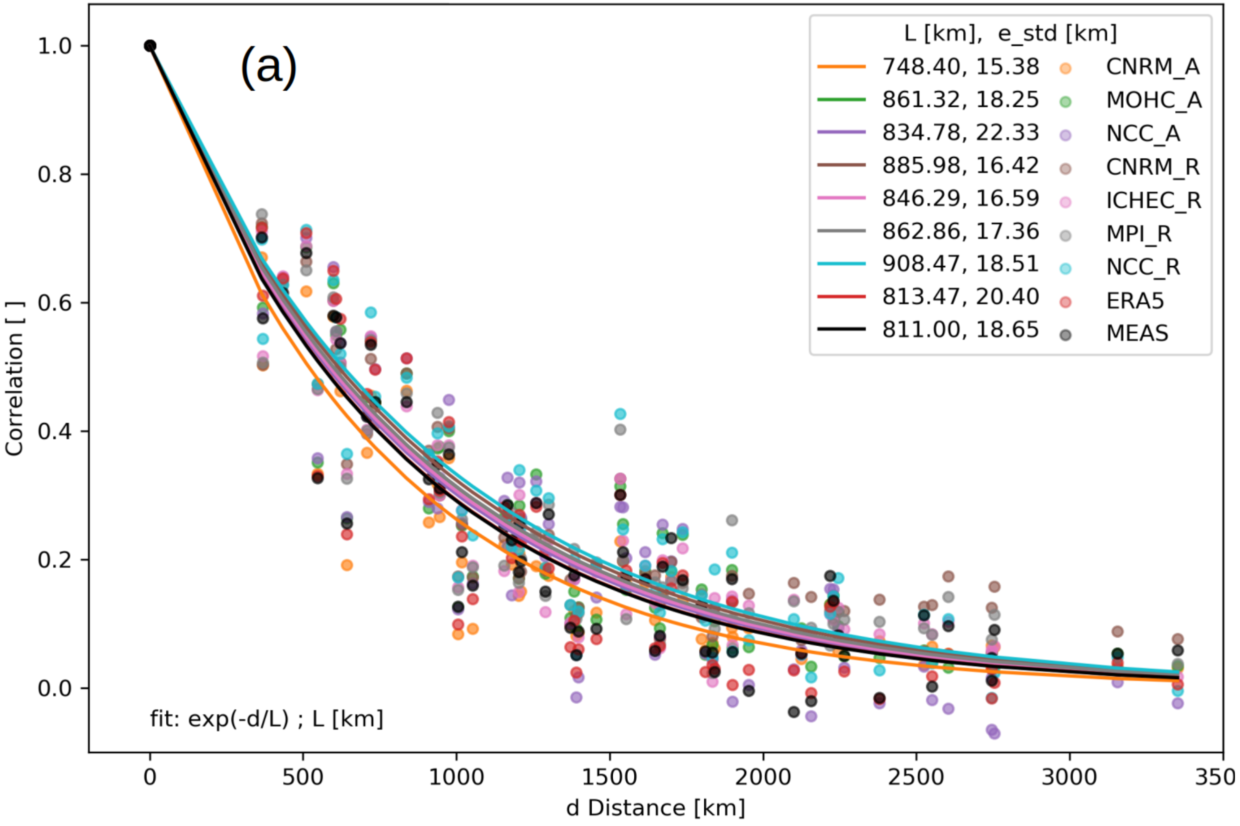
uncorrected

Capacity factor (CF) error computed by the difference measured minus simulated CF for all 12 European countries and ERA5 and EURO-CORDEX models. GWA2 scales the top 7 models (names starting with ‘‘g’’).

The last two columns show the mean and the standard deviation for all countries.

Luzia et al (2023)

Spatial correlations in the Euro-CORDEX models
Wind power generation (measurements vs models), 12 countries



Luzia et al (2023)

wind speed (OBS, models)

↓

database of wind power installations

↓

wind power generation

aggregate by country

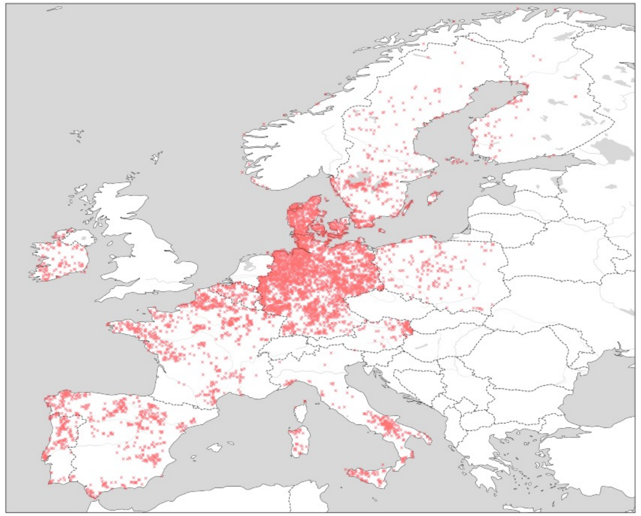


Fig. 2. Location of wind power plants operating in 2018.

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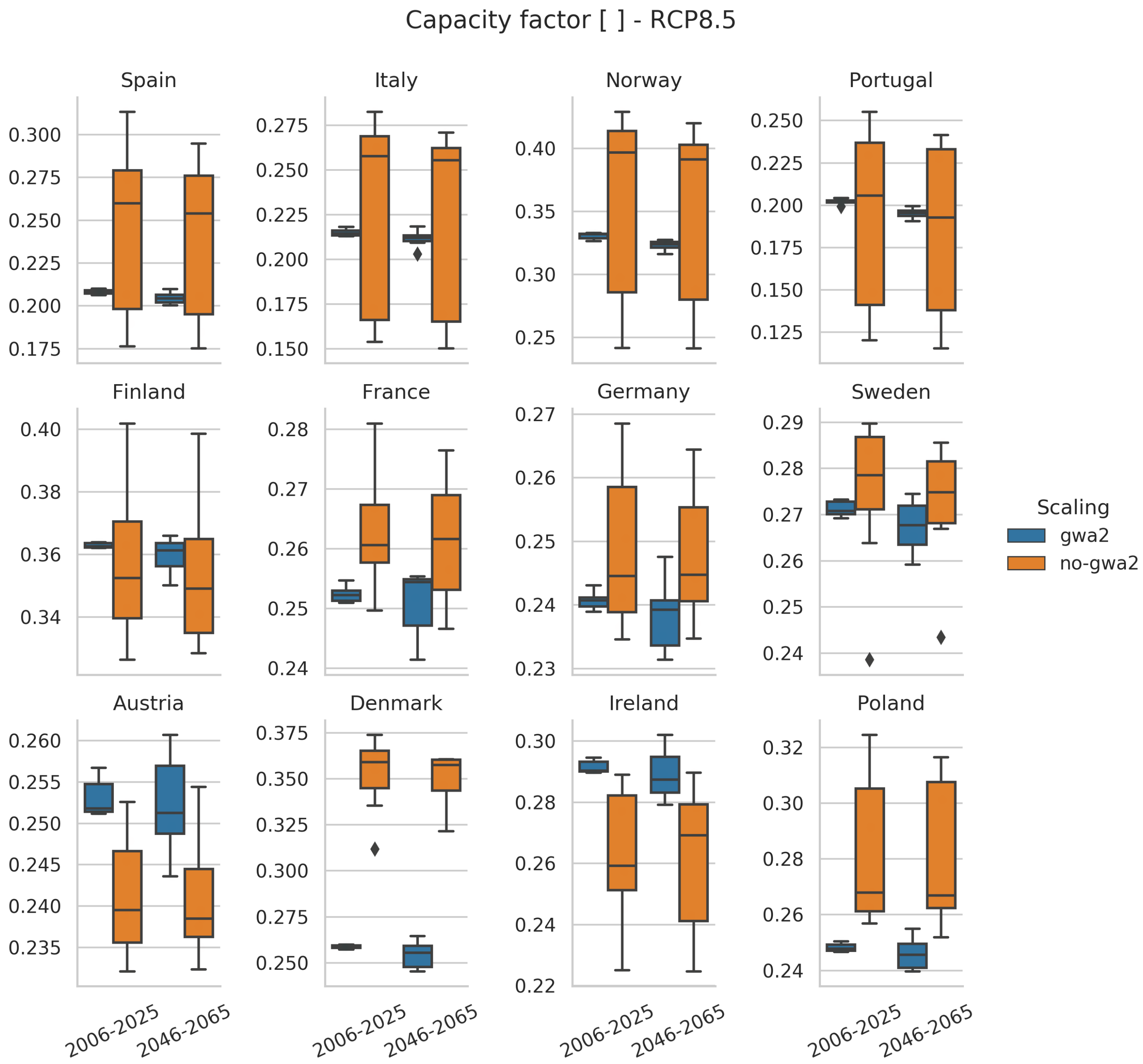
The future of energy production in Europe according to CORDEX

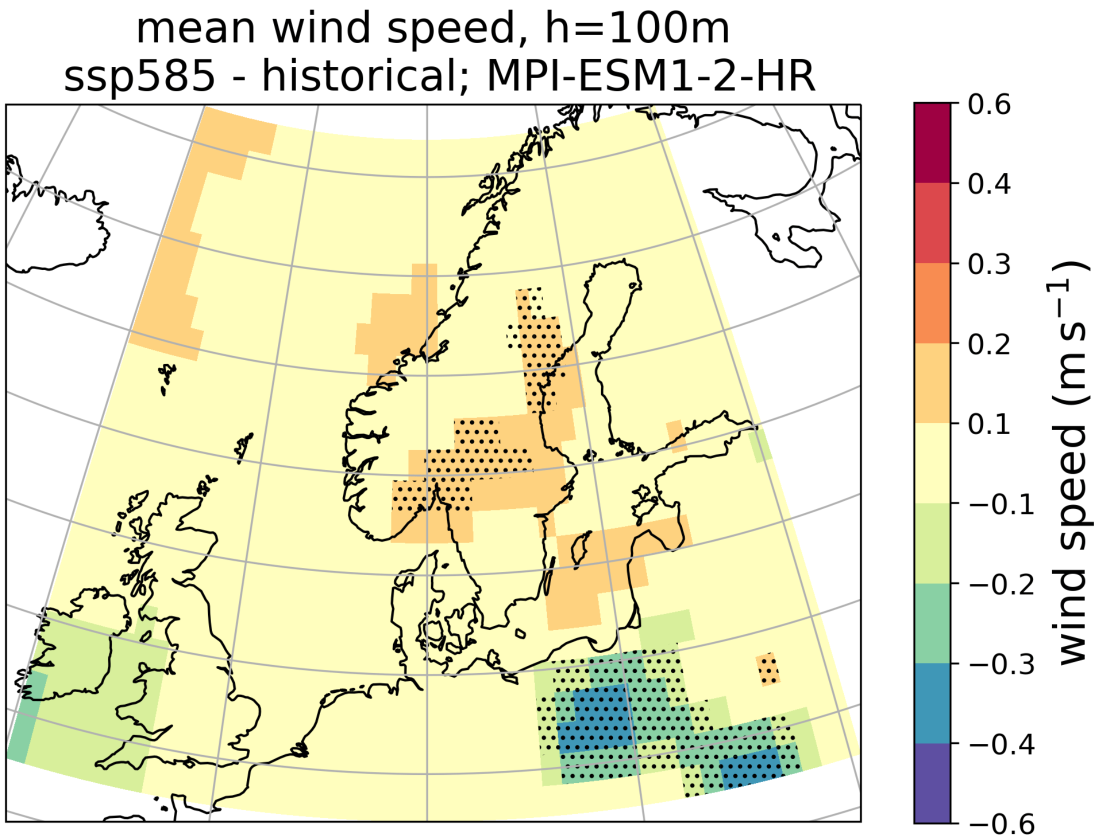
Raw versus bias-corrected (using Global Wind Atlas wind speeds); 2006-2025 compared to 2046-2065



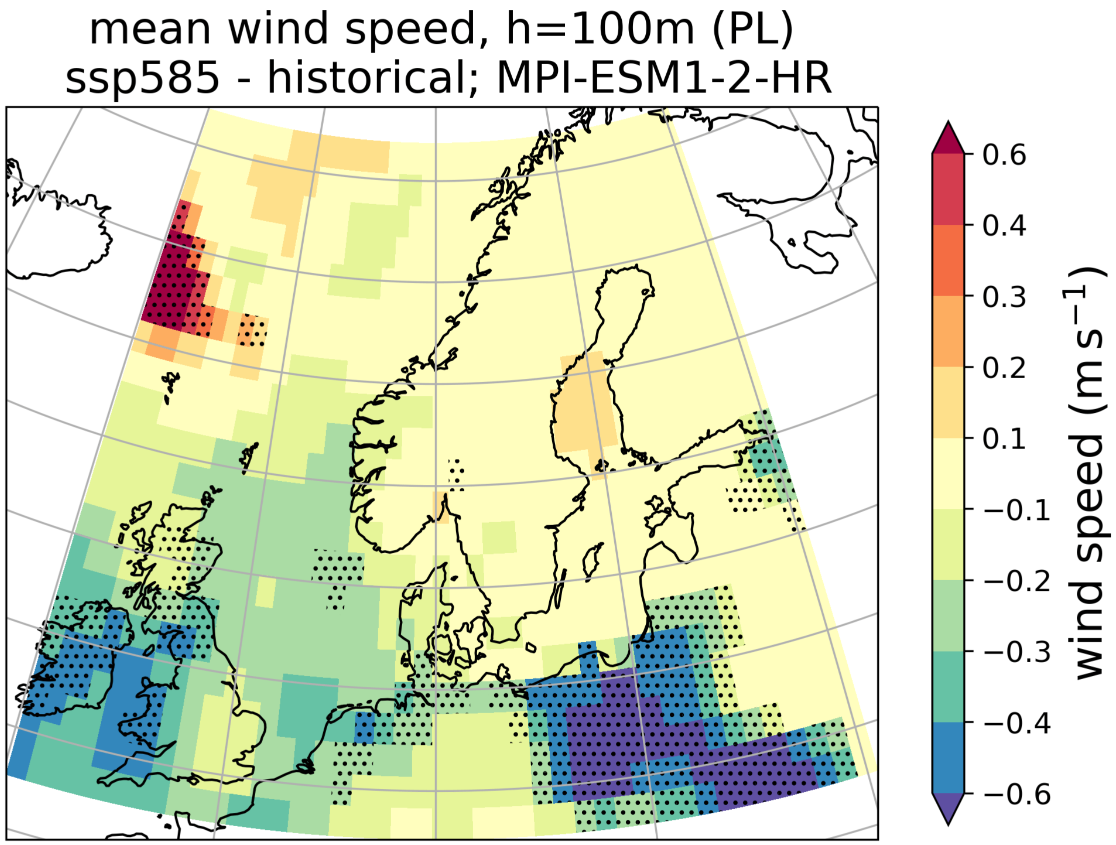
Final thoughts…

- Extrapolating wind speeds from 10 meters to turbine height using a constant exponent power law is a poor approximation and will often exaggerate future changes in wind resources. **Please include at least the wind speed and direction at 100 m in the new CORDEX runs.**

Wind Extrapolation, future – past wind speed, 100 m



Interpolation from model levels



Vertical extrapolation from wind speed at 10-meters

$$U_{100} = U_{10}\left(\frac{100}{10}\right)^{\alpha}$$

$$\text{where}\, \alpha = 1/7$$

Final thoughts…

- Extrapolating wind speeds from 10 meters to turbine height using a constant exponent power law is a poor approximation and will often exaggerate future changes in wind resources. **Please include at least the wind speed and direction at 100 m in the new CORDEX runs.**
- The **full chain of models** is necessary to understand the effects of climate change on future power generation. Simple approximations are often misleading.
- Wind speeds from CORDEX represent the power generation in Europe very well when biased-corrected using the GWA (other studies also). **But more models and scenarios are needed.**
- Other variables are also used in power system models, including solar PV, electric & heat demand and hydropower simulation.

References

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