CorRES tool: Modelling VRE variability and uncertainty

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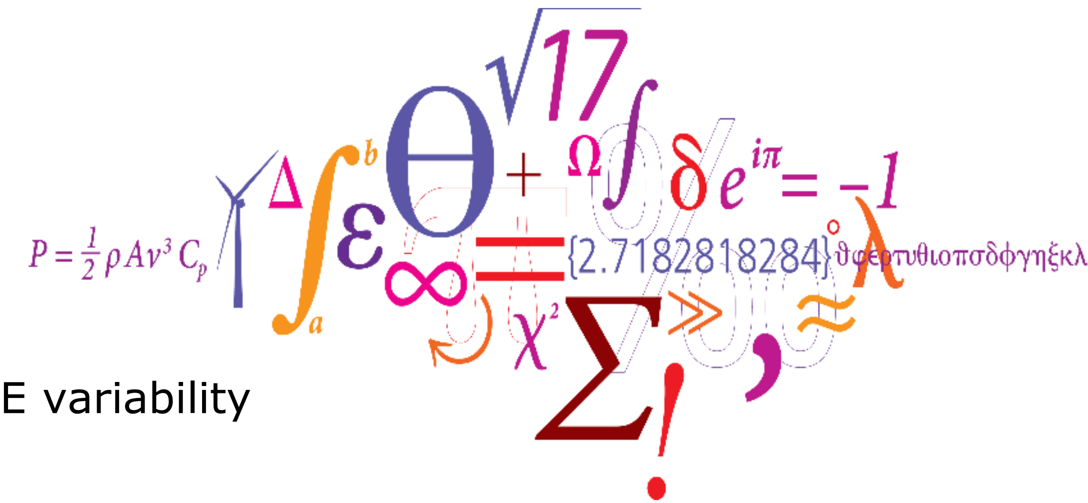


NSON-DK webinar: Modelling VRE variability and uncertainty
29 April 2019

DTU Wind Energy
Department of Wind Energy

CorRES

- CorRES[1] (Correlations in Renewable Energy Sources)
  - Developed at DTU Wind Energy
  - Simulation tool for variable renewable energy (VRE) generation
  - **Models both wind and solar PV generation**

- **Based on meteorological reanalysis data**
  - 35 years of hourly data covering Europe
  - Also other geographical regions (e.g., South Africa, India planned)

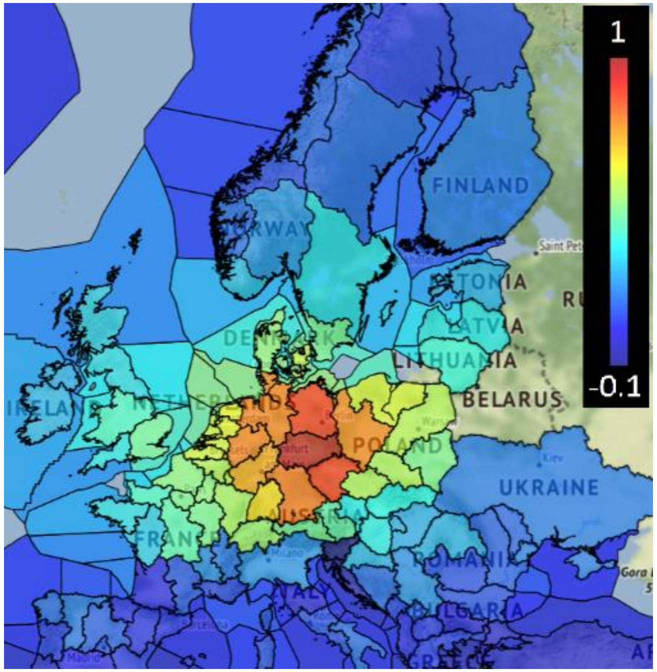
- Used in many projects
  - Danish and International research projects: e.g., NSON-DK, Flex4RES
  - Pan-European VRE generation simulations for ENTSO-E
    - Used in the modelling for TYNDP

[1]M. Koivisto et al., “Using time series simulation tool for assessing the effects of variable renewable energy generation on power and energy systems”, *WIREs Energy and Environment*, e329, 2018 (https://doi.org/10.1002/wene.329)

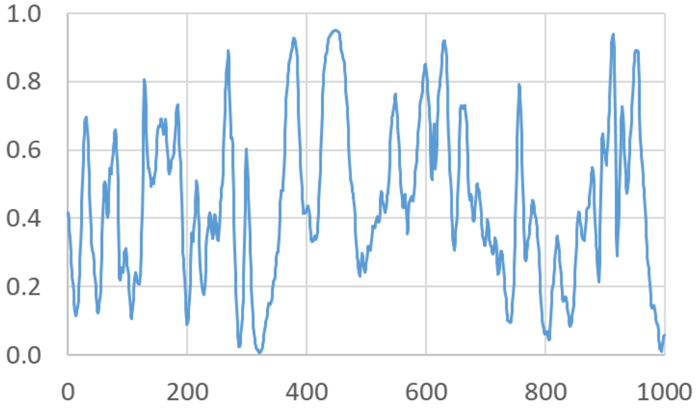
CorRES: VRE variability

- The reanalysis data provide the main spatiotemporal dependencies for the simulations
  - Enable simulation of large geographical areas[1]
  - Stochastic simulations model short-term variability in more detail

- Can be used, e.g., in
  - **Transmission expansion studies**
  - **Assessing system adequacy**



Spatial correlations in wind generation looking from a German onshore region (35 simulation years)



Example 1000 hours of simulated wind generation (Denmark onshore)

[1]E. Nuño et al., "Simulation of transcontinental wind and solar PV generation time series", *Renewable Energy*, vol. 118, pp. 425-436, April 2018 (https://doi.org/10.1016/j.renene.2017.11.039).

Reanalysis data and mesoscale downscaling

- CorRES is based on ERA Interim Reanalysis
  - **Move to ERA-5 is planned** (testing underway)

- Meteorological time series are obtained from the **Weather Research and Forecasting (WRF) model**
  - WRF modelling carried out at DTU Wind Energy (Resource Assessment Modelling section)
  - Mesoscale downscaling[1,2] is applied to generate time series of the meteorological fields
  - Wind speed and direction, irradiance, temperature…

[1]A. N. Hahmann et al., "A Reanalysis System for the Generation of Mesoscale Climatographies", *Journal of Applied Meteorology and Climatology*, pp. 954-972, May 2010 (https://doi.org/10.1175/2009JAMC2351.1).

[2]A. N. Hahmann et al., "Wind climate estimation using WRF model output: method and model sensitivities over the sea," *International Journal of Climatology*, vol. 35, no. 12, p. 3422–3439, October 2015 (https://doi.org/10.1002/joc.4217).

Information about the reanalysis datasets: https://www.ecmwf.int/en/forecasts/datasets/browse-reanalysis-datasets

Statistical downscaling (bias correction)

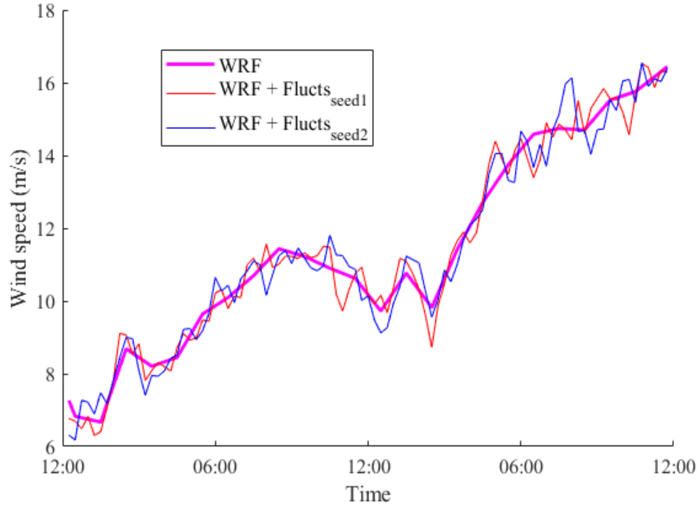
- Using reanalysis data directly may cause significant errors in simulated capacity factors
  - Caused by incorrect means in the meteorological time series (bias)
  - Even if mesoscale downscaling is used
- To correct this, CorRES includes **calibration based on historical data**
  - Based, e.g., on annual capacity factors
  - Generation time series can also be used

- **Important to have correct technical parameters in the simulations**[1]
  - Locations of installations, hub heights, turbine types…
  - Otherwise bias correction may accidentally try to fix other issues than meteorological data biases

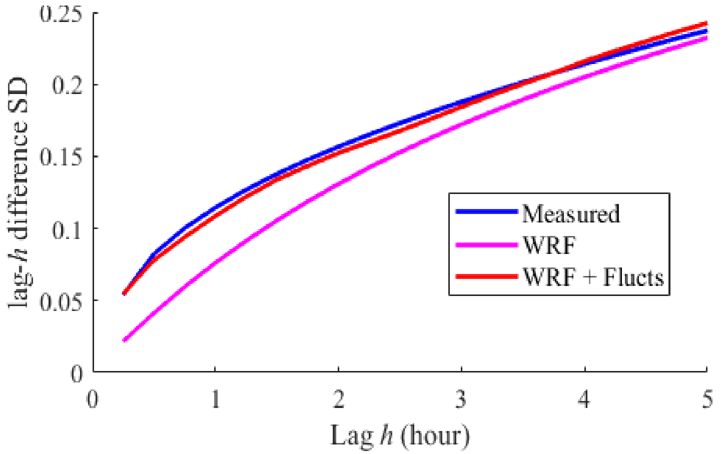
[1]M. Koivisto et al., "Large-scale wind generation simulations: From the analysis of current installations to modelling the future", *Journal of Physics: Conference Series*, vol. 1102, no. 1, 012034, 2018 (https://doi.org/10.1088/1742-6596/1102/1/012034).

High frequency (sub-hourly) simulations

- The reanalysis approach can capture most large-scale variability
  - **However, variations are smoothened because of averaging effects in mesoscale models**[1]
- CorRES utilizes stochastic simulation modelling to better model the high frequency variability[2]
  - Called fluctuations
  - They are combined to the WRF reanalysis data



EARLY RESULTS (TO BE PUBLISHED)

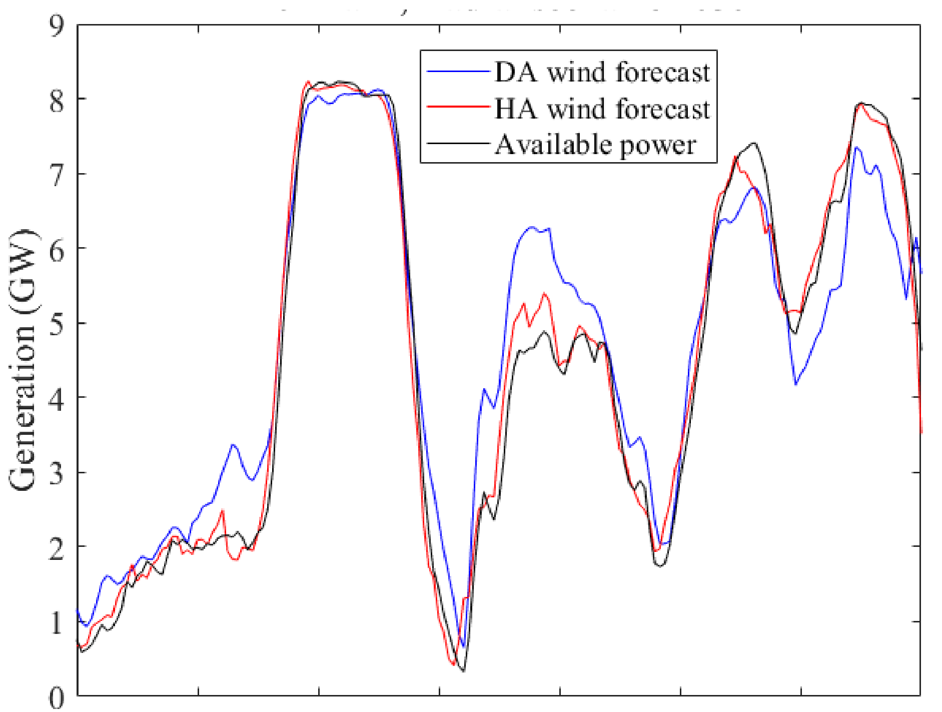


[1]X. G. Larsén et al., "Recipes for correcting the impact of effective mesoscale resolution on the estimation of extreme winds," *Journal of Applied Meteorology and Climatology*, pp. 521-533, March 2012.

[2]P. Sørensen et al., "Modelling of Power Fluctuations from Large Offshore Wind Farms", *Wind Energy*, vol. 11, no. 1, pp. 29-43. February 2008 (https://doi.org/10.1002/we.246)

CorRES: VRE forecast uncertainty

- In addition to VRE generation, **CorRES can simulate VRE forecasts**
- Based on multivariate ARMA time series simulation
  - The forecast error simulation model for solar PV is a recent addition[1]
- Can be used, e.g., in
  - **Assessing balancing needs**
  - **Power system stability studies**



Example regional simulation of available wind generation and forecasts (DA = day-ahead; HA = hour-ahead)

[1]E. Nuño et al, "On the simulation of aggregated solar PV forecast errors", *IEEE Transactions on Sustainable Energy*, vol. 9, no. 4, pp. 1889-1898, October 2018 (https://doi.org/10.1109/TSTE.2018.2818727)

CorRES developments

- Ongoing:
  - Move to ERA-5 reanalysis data
  - Link mesoscale WRF wind speeds to microscale data
    - **Microscale data from GWA** (https://globalwindatlas.info)
  - Farm-level power curve for each simulated wind power plant

- In upcoming projects:
  - High frequency simulation capability for solar PV
    - Currently for wind only
  - Combine wind and solar PV forecast error simulation models
    - To capture joint uncertainties
  - **Include expected climate change effects to WRF simulations**
    - For modelling future scenarios (e.g., 2040, 2050)
    - Addition to using historical reanalysis data
    - Part of the 3-year PSfuture project starting in July 2019 (La Cour Fellowship funding from DTU Wind Energy)

Some example large-scale CorRES runs and applications

Understanding correlations between VRE sources

- Variance of aggregate VRE generation is affected by[1]
  - **Share of wind and solar PV**
  - **Geographical distribution of VRE installations**

		Onshore wind										Offshore wind										Solar PV									
		DE	DK	EE	FI	LT	LV	NL	NO	PL	SE	DE	DK	EE	FI	LT	LV	NL	NO	PL	SE	DE	DK	EE	FI	LT	LV	NL	NO	PL	SE
Onshore wind	DE		0.66	0.25	0.14	0.40	0.35	0.80	0.26	0.69	0.36	0.72	0.61	0.21	0.11	0.37	0.34	0.67	0.07	0.50	0.32	-0.21	-0.22	-0.22	-0.23	-0.22	-0.22	-0.21	-0.21	-0.20	-0.23
	DK	0.66		0.26	0.18	0.39	0.39	0.52	0.45	0.56	0.57	0.73	0.86	0.25	0.16	0.36	0.35	0.53	0.14	0.54	0.43	-0.07	-0.11	-0.10	-0.13	-0.11	-0.10	-0.07	-0.11	-0.07	-0.12
	EE	0.25	0.26		0.56	0.55	0.72	0.19	0.26	0.37	0.54	0.19	0.23	0.82	0.48	0.54	0.63	0.16	0.16	0.36	0.47	-0.12	-0.14	-0.18	-0.19	-0.16	-0.16	-0.12	-0.15	-0.13	-0.16
	FI	0.14	0.18	0.56		0.25	0.36	0.11	0.37	0.18	0.58	0.12	0.16	0.46	0.87	0.26	0.33	0.10	0.29	0.18	0.49	-0.09	-0.11	-0.13	-0.17	-0.12	-0.12	-0.09	-0.14	-0.10	-0.13
	LT	0.40	0.39	0.55	0.25		0.86	0.26	0.22	0.68	0.51	0.29	0.35	0.56	0.22	0.86	0.76	0.23	0.08	0.63	0.40	-0.14	-0.15	-0.18	-0.18	-0.18	-0.18	-0.14	-0.16	-0.15	-0.17
	LV	0.35	0.39	0.72	0.36	0.86		0.24	0.26	0.57	0.59	0.27	0.34	0.74	0.32	0.81	0.88	0.21	0.13	0.57	0.48	-0.09	-0.11	-0.15	-0.16	-0.14	-0.14	-0.09	-0.12	-0.10	-0.13
	NL	0.80	0.52	0.19	0.11	0.26	0.24		0.25	0.42	0.27	0.72	0.50	0.15	0.09	0.25	0.24	0.84	0.08	0.32	0.24	-0.16	-0.19	-0.17	-0.19	-0.17	-0.17	-0.17	-0.18	-0.15	-0.19
	NO	0.26	0.45	0.26	0.37	0.22	0.26	0.25		0.22	0.52	0.35	0.41	0.24	0.35	0.20	0.22	0.28	0.70	0.21	0.32	-0.13	-0.17	-0.18	-0.22	-0.17	-0.18	-0.14	-0.23	-0.14	-0.20
	PL	0.69	0.56	0.37	0.18	0.68	0.57	0.42	0.22		0.49	0.47	0.53	0.35	0.15	0.63	0.54	0.36	0.07	0.78	0.42	-0.20	-0.20	-0.23	-0.23	-0.23	-0.23	-0.19	-0.20	-0.21	-0.22
	SE	0.36	0.57	0.54	0.58	0.51	0.59	0.27	0.52	0.49		0.37	0.53	0.56	0.55	0.49	0.53	0.26	0.32	0.52	0.77	-0.15	-0.18	-0.20	-0.23	-0.19	-0.19	-0.15	-0.21	-0.16	-0.21
Offshore wind	DE	0.72	0.73	0.19	0.12	0.29	0.27	0.72	0.35	0.47	0.37		0.78	0.18	0.10	0.28	0.26	0.86	0.11	0.43	0.31	-0.13	-0.16	-0.15	-0.16	-0.14	-0.15	-0.14	-0.16	-0.12	-0.17
	DK	0.61	0.86	0.23	0.16	0.35	0.34	0.50	0.41	0.53	0.53	0.78		0.22	0.16	0.36	0.34	0.57	0.13	0.54	0.43	-0.12	-0.15	-0.14	-0.14	-0.12	-0.14	-0.14	-0.17	-0.11	-0.16
	EE	0.21	0.25	0.82	0.46	0.56	0.74	0.15	0.24	0.35	0.56	0.18	0.22		0.41	0.54	0.65	0.14	0.15	0.35	0.47	-0.15	-0.16	-0.19	-0.20	-0.18	-0.18	-0.13	-0.16	-0.15	-0.17
	FI	0.11	0.16	0.48	0.87	0.22	0.32	0.09	0.35	0.15	0.55	0.10	0.16	0.41		0.24	0.33	0.09	0.29	0.16	0.47	-0.09	-0.11	-0.12	-0.15	-0.11	-0.11	-0.09	-0.13	-0.09	-0.13
	LT	0.37	0.36	0.54	0.26	0.86	0.81	0.25	0.20	0.63	0.49	0.28	0.36	0.54	0.24		0.80	0.22	0.09	0.64	0.41	-0.16	-0.17	-0.19	-0.18	-0.17	-0.19	-0.16	-0.18	-0.16	-0.19
	LV	0.34	0.35	0.63	0.33	0.76	0.88	0.24	0.22	0.54	0.53	0.26	0.34	0.65	0.33	0.80		0.22	0.13	0.54	0.44	-0.07	-0.09	-0.12	-0.11	-0.08	-0.11	-0.10	-0.11	-0.08	-0.11
	NL	0.67	0.53	0.16	0.10	0.23	0.21	0.84	0.28	0.36	0.26	0.86	0.57	0.14	0.09	0.22	0.22		0.09	0.30	0.23	-0.11	-0.15	-0.14	-0.15	-0.13	-0.13	-0.13	-0.15	-0.11	-0.15
	NO	0.07	0.14	0.16	0.29	0.08	0.13	0.08	0.70	0.07	0.32	0.11	0.13	0.15	0.29	0.09	0.13	0.09		0.07	0.18	-0.07	-0.10	-0.12	-0.14	-0.10	-0.11	-0.08	-0.16	-0.09	-0.13
	PL	0.50	0.54	0.36	0.18	0.63	0.57	0.32	0.21	0.78	0.52	0.43	0.54	0.35	0.16	0.64	0.54	0.30	0.07		0.43	-0.13	-0.14	-0.16	-0.16	-0.16	-0.16	-0.12	-0.13	-0.14	-0.16
	SE	0.32	0.43	0.47	0.49	0.40	0.48	0.24	0.32	0.42	0.77	0.31	0.43	0.47	0.47	0.41	0.44	0.23	0.18	0.43		-0.11	-0.13	-0.15	-0.17	-0.15	-0.14	-0.10	-0.14	-0.12	-0.15
Solar PV	DE	-0.21	-0.07	-0.12	-0.09	-0.14	-0.09	-0.16	-0.13	-0.20	-0.15	-0.13	-0.12	-0.15	-0.09	-0.16	-0.07	-0.11	-0.07	-0.13	-0.11		0.94	0.90	0.85	0.88	0.92	0.92	0.90	0.96	0.94
	DK	-0.22	-0.11	-0.14	-0.11	-0.15	-0.11	-0.19	-0.17	-0.20	-0.18	-0.16	-0.15	-0.16	-0.11	-0.17	-0.09	-0.15	-0.10	-0.14	-0.13	0.94		0.91	0.87	0.88	0.91	0.90	0.93	0.93	0.96
	EE	-0.22	-0.10	-0.18	-0.13	-0.18	-0.15	-0.17	-0.18	-0.23	-0.20	-0.15	-0.14	-0.19	-0.12	-0.19	-0.12	-0.14	-0.12	-0.16	-0.15	0.90	0.91		0.91	0.91	0.98	0.86	0.91	0.93	0.94
	FI	-0.23	-0.13	-0.19	-0.17	-0.18	-0.16	-0.19	-0.22	-0.23	-0.23	-0.16	-0.14	-0.20	-0.15	-0.18	-0.11	-0.15	-0.14	-0.16	-0.17	0.85	0.87	0.91		0.92	0.90	0.75	0.85	0.87	0.91
	LT	-0.22	-0.11	-0.16	-0.12	-0.18	-0.14	-0.17	-0.17	-0.23	-0.19	-0.14	-0.12	-0.18	-0.11	-0.17	-0.08	-0.13	-0.10	-0.16	-0.15	0.88	0.88	0.91	0.92		0.94	0.77	0.84	0.92	0.90
	LV	-0.22	-0.10	-0.16	-0.12	-0.18	-0.14	-0.17	-0.18	-0.23	-0.19	-0.15	-0.14	-0.18	-0.11	-0.19	-0.11	-0.13	-0.11	-0.16	-0.14	0.92	0.91	0.98	0.90	0.94		0.87	0.91	0.94	0.94
	NL	-0.21	-0.07	-0.12	-0.09	-0.14	-0.09	-0.17	-0.14	-0.19	-0.15	-0.14	-0.14	-0.13	-0.09	-0.16	-0.10	-0.13	-0.08	-0.12	-0.10	0.92	0.90	0.86	0.75	0.77	0.87		0.90	0.90	0.89
	NO	-0.21	-0.11	-0.15	-0.14	-0.16	-0.12	-0.18	-0.23	-0.20	-0.21	-0.16	-0.17	-0.16	-0.13	-0.18	-0.11	-0.15	-0.16	-0.13	-0.14	0.90	0.93	0.91	0.85	0.84	0.91	0.90		0.91	0.95
	PL	-0.20	-0.07	-0.13	-0.10	-0.15	-0.10	-0.15	-0.14	-0.21	-0.16	-0.12	-0.11	-0.15	-0.09	-0.16	-0.08	-0.11	-0.09	-0.14	-0.12	0.96	0.93	0.93	0.87	0.92	0.94	0.90	0.91		0.94
	SE	-0.23	-0.12	-0.16	-0.13	-0.17	-0.13	-0.19	-0.20	-0.22	-0.21	-0.17	-0.16	-0.17	-0.13	-0.19	-0.11	-0.15	-0.13	-0.16	-0.15	0.94	0.96	0.94	0.91	0.90	0.94	0.89	0.95	0.94	

Correlations between VRE sources[1]

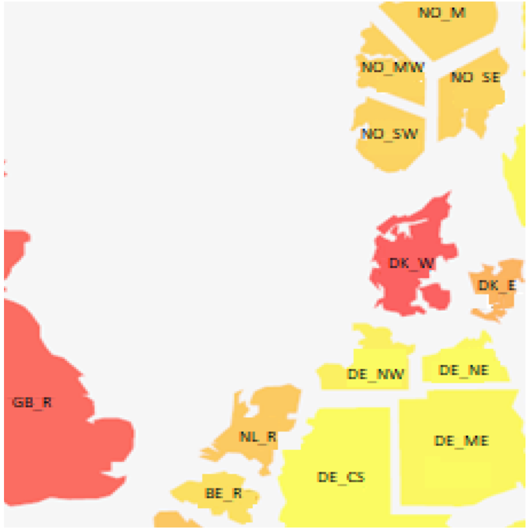
[1]M. Koivisto et al., "Minimizing Variance in Variable Renewable Energy Generation in Northern Europe", *IEEE International Conference on Probabilistic Methods Applied to Power Systems*, Boise, Idaho USA, June, 2018 (https://doi.org/10.1109/PMAPS.2018.8440369)

Energy system investment optimization

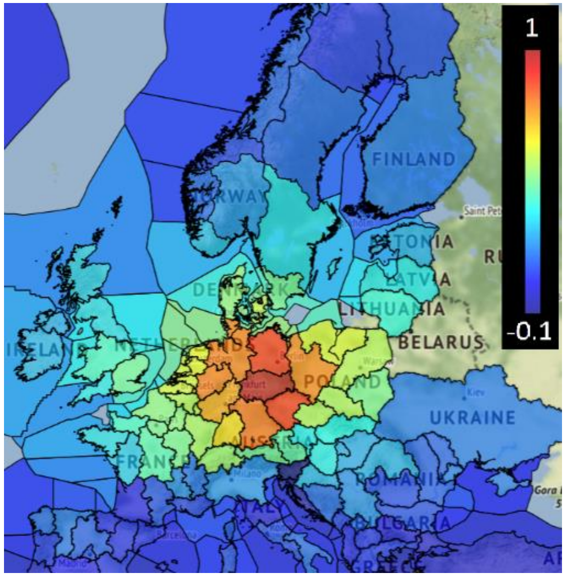
- CorRES provides the wind and solar generation time series
  - Investment optimization, e.g., using the Balmorel model (www.balmorel.com)

- Large-scale investment modelling carried out in multiple projects, such as:
  - Flex4RES (www.nordicenergy.org/flagship/flex4res/)
  - NSON-DK (http://www.nson-dk-project.dk/)
    - Some early results available[1]

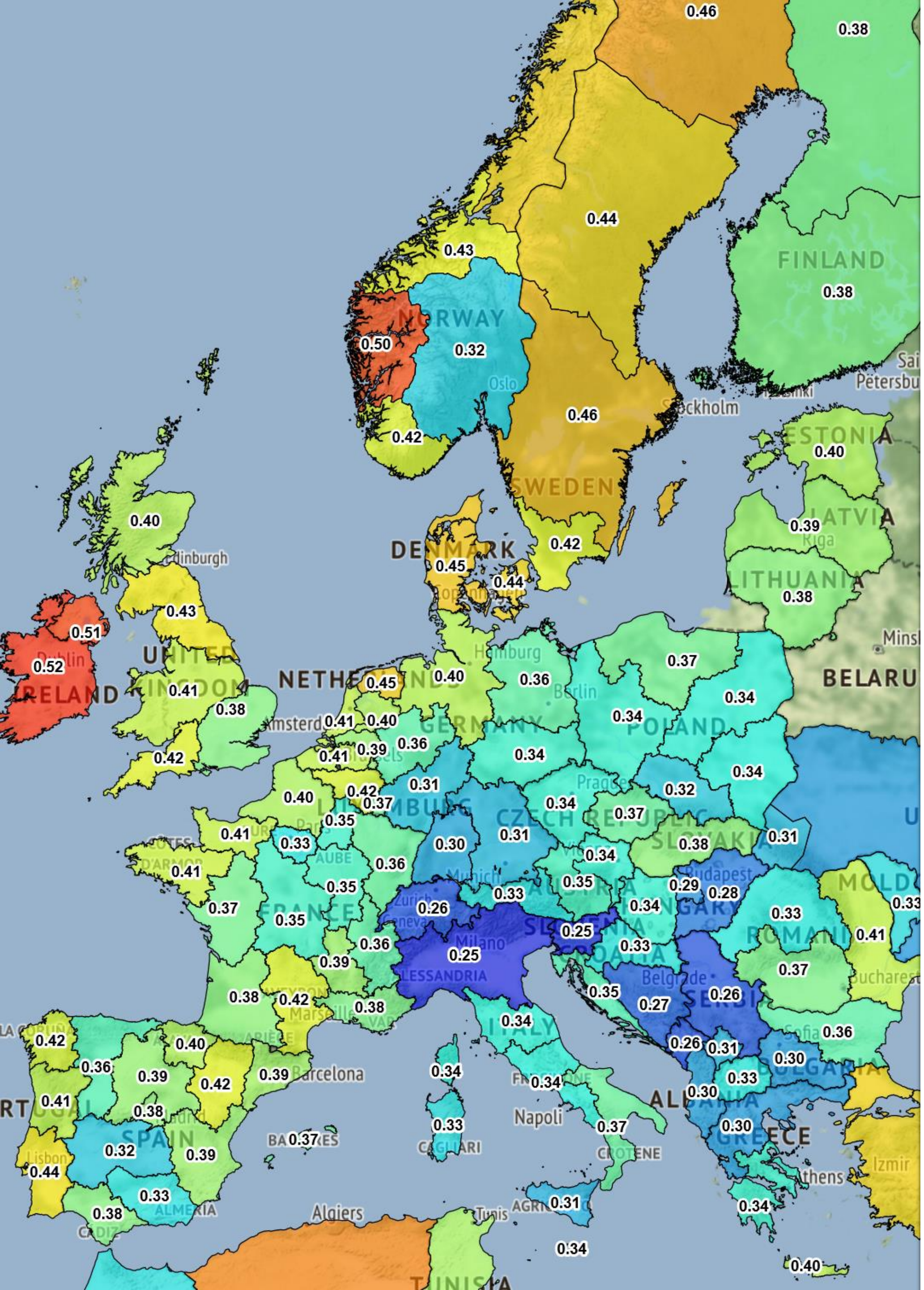
[1]M. Koivisto et al., "North Sea offshore Grid development: Combined optimization of grid and generation investments towards 2050," *Wind Integration Workshop*, Stockholm, Sweden, October 2018 (http://orbit.dtu.dk/files/158926186/4C_4_WIW18_142_paper_Matti_Koivisto.pdf)



Regions with investment optimization in the NSON-DK project



Spatial correlations in wind generation (from a German region)



2050 pan-European scenario

Onshore wind

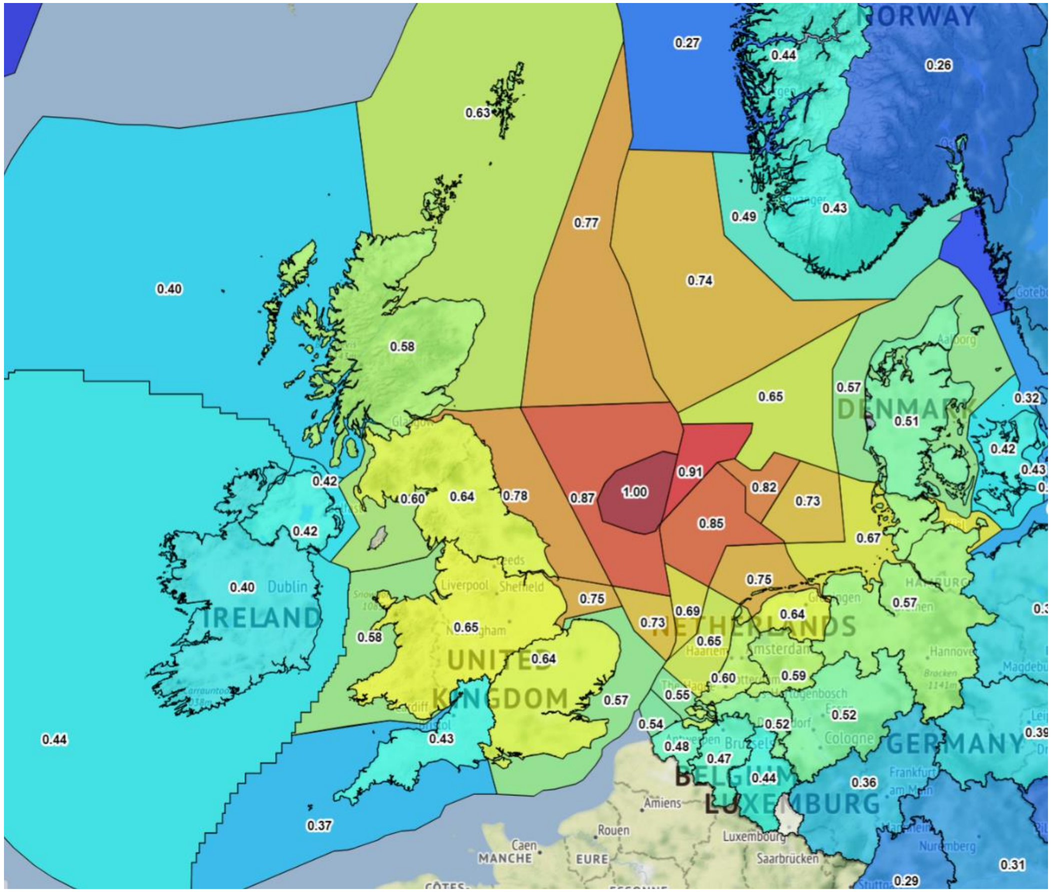
CFs are averages of 35 meteorological years

In 2050, all onshore regions are assumed to reach an average hub height of 120 m (also lower specific power)

Some things to be checked:

1. Swedish CFs are high
2. UK CFs (except NI) are a bit low

Ongoing work: More detailed modelling of the North Sea region



Correlations from a possible DoggerBank area to other regions