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30 GW Offshore wind in Norway – wind power correlations and smoothing effects

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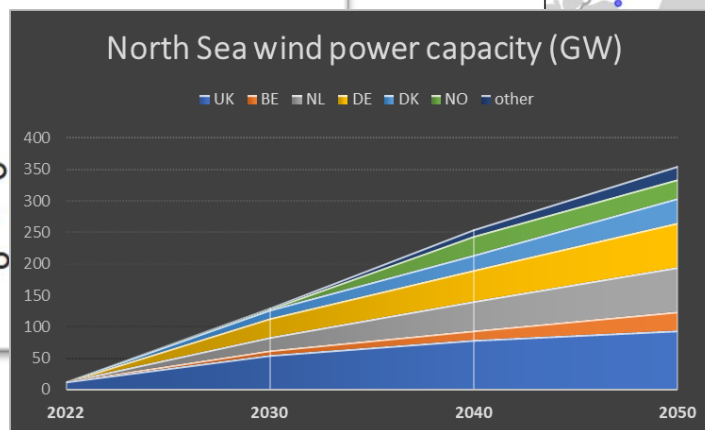
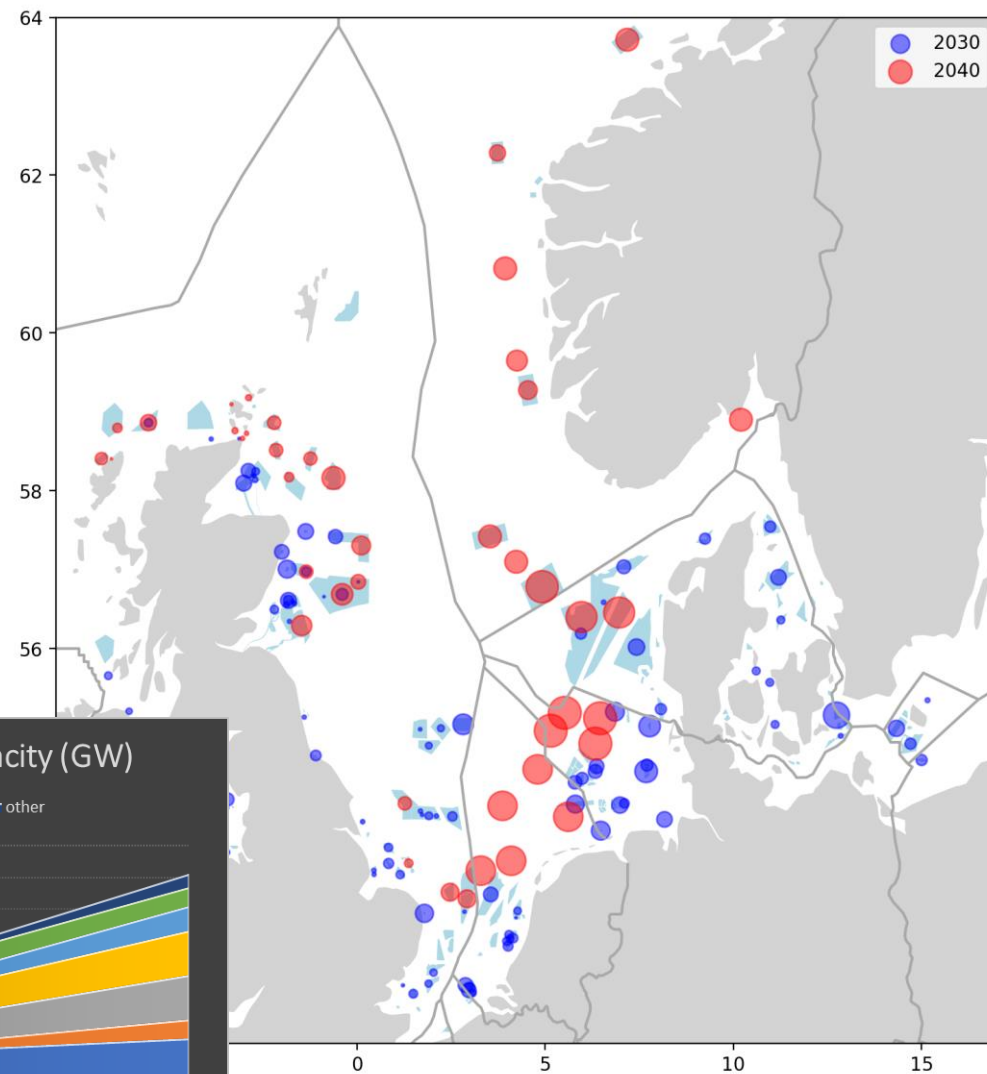
Norway sets 30GW offshore wind energy target



Photo by Anne Kristin Hjukse at the Norwegian Prime Ministers Office

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Norwegian Prime Minister Jonas Gahr Støre announced at a press conference this week that the Government has designated areas for 30,000 MW (30 GW) for offshore wind power by 2040.





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Motivation

30 GW will give 130 TWh/year, similar to present hydro power system

- Can we by studying wind power time-series say something about its impact on the system?
 - Variability and need for balancing on short and long time scales
 - Correlations as a proxy for *achieved price* or “cannibalisation” effect



<https://www.northwindresearch.no/>



<https://oceangridproject.no/>



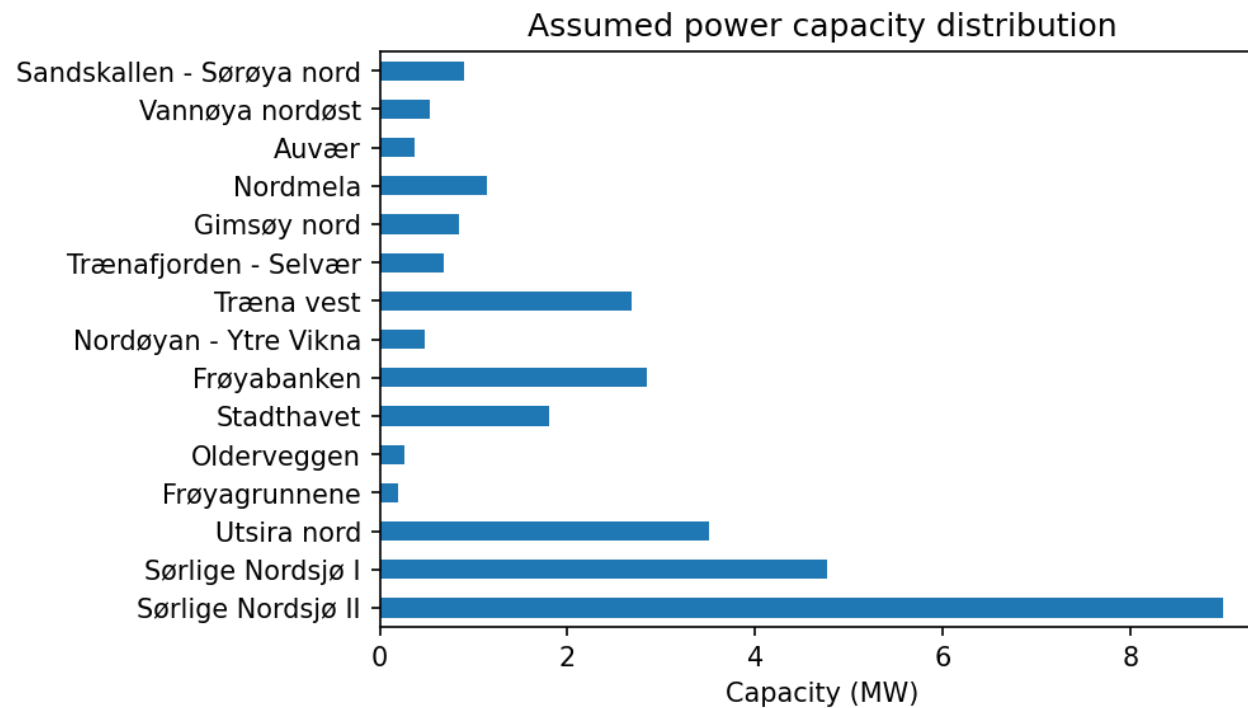
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30 GW offshore wind in Norway

Time-series study



Assumption:
30 GW capacity distributed according to area
(NVE 2012 sites):



Included for comparison

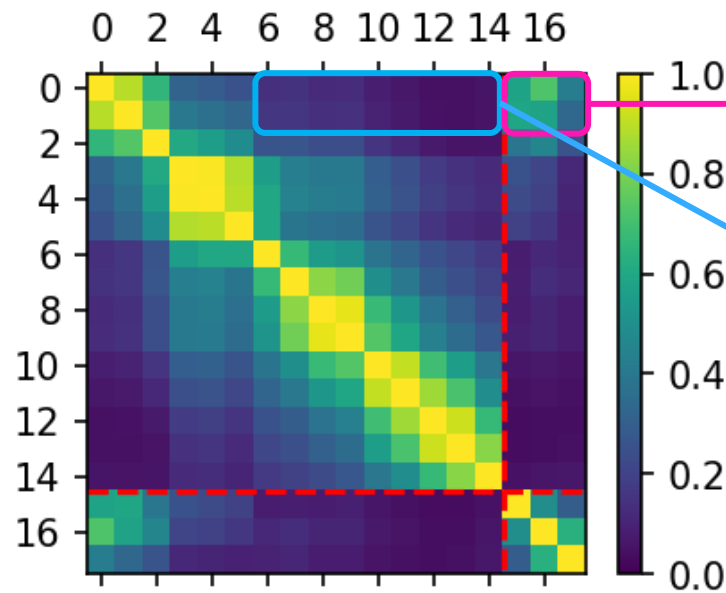


Approach

- 29 years of hourly wind speed data at selected locations
 - MERRA-2 Reanalysis data
- Converted to wind power
 - effective power curve representing wind farm (Gauss filter on top of a single turbine power curve)
- Statistical analysis
 - Compute and plot various metrics of general interest

Correlation of wind power at different sites

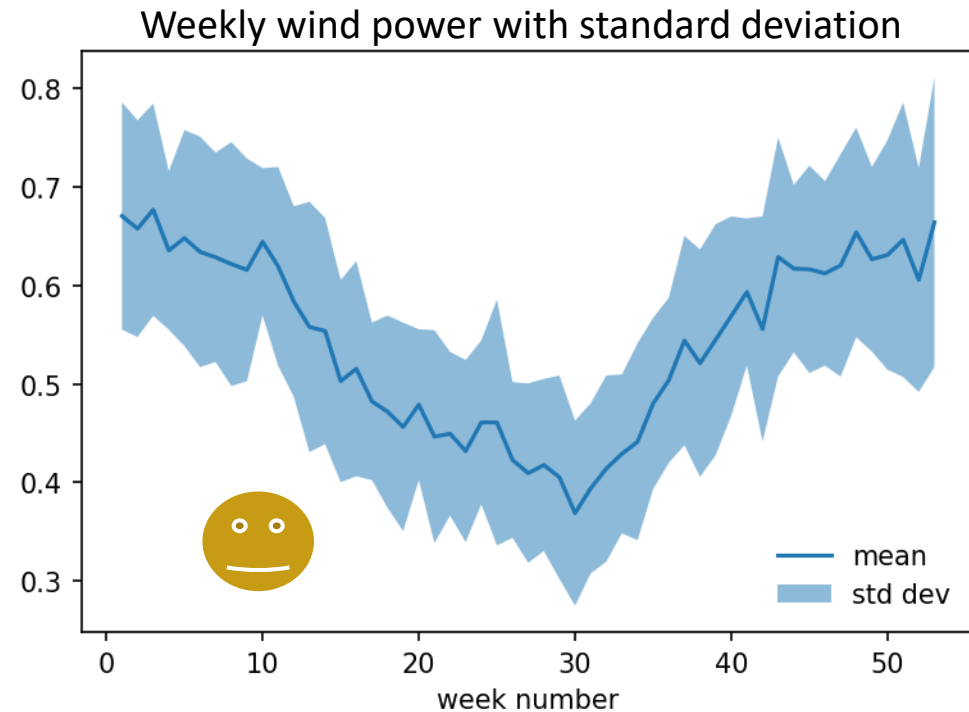
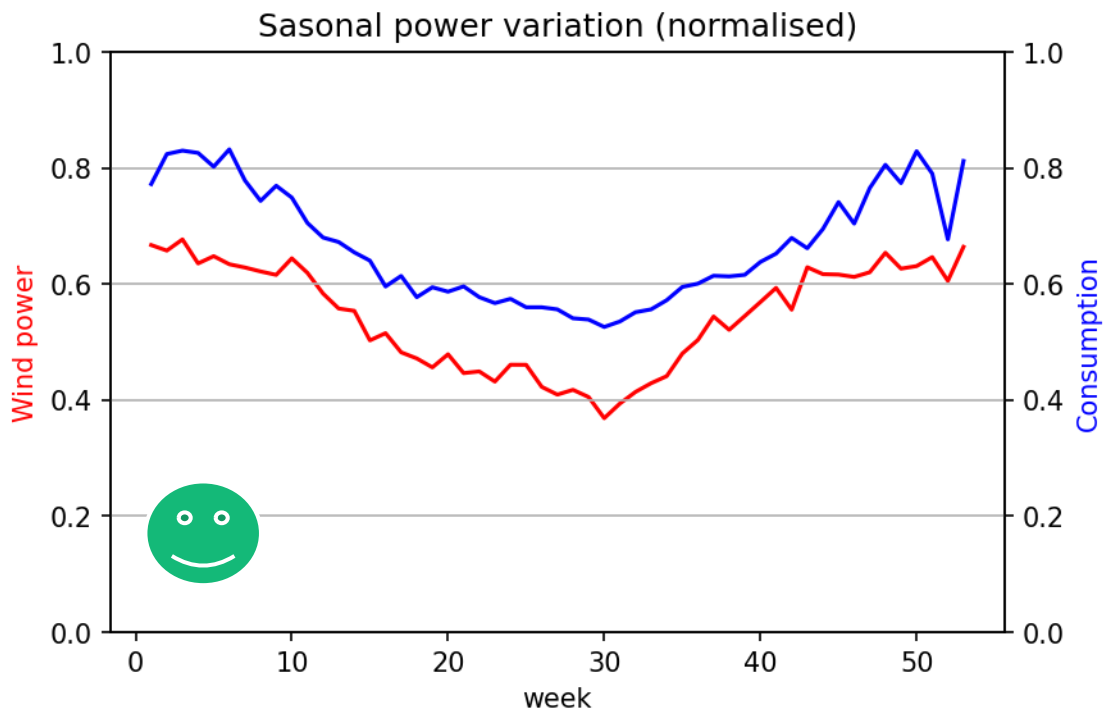
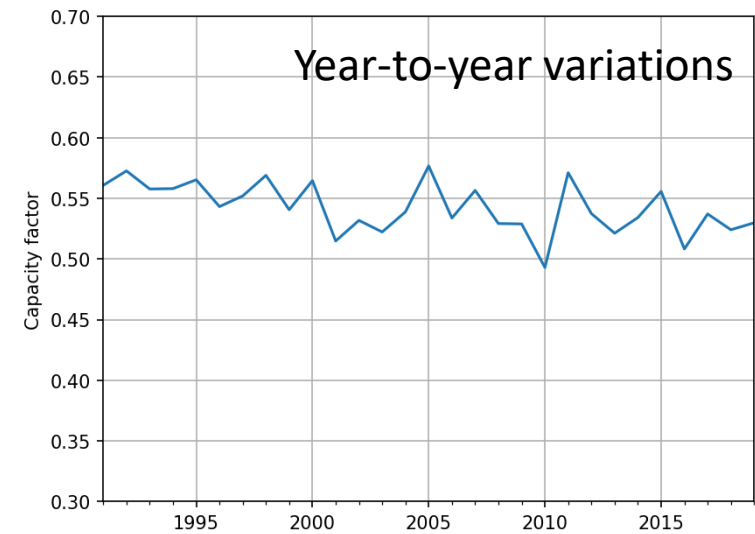
+1: perfectly correlated
 0: uncorrelated
 -1: perfectly anti-correlated



- Correlation coefficients – hour-by-hour power output at different wind farms
- Sørliche Nordsjø vs Europe: High (0.34-0.73)
- Sørliche Nordsjø vs Frøyabanken and farther north : Low (<0.15)
- Similar result when looking at day-by-day average values



Seasonal variation Wind power

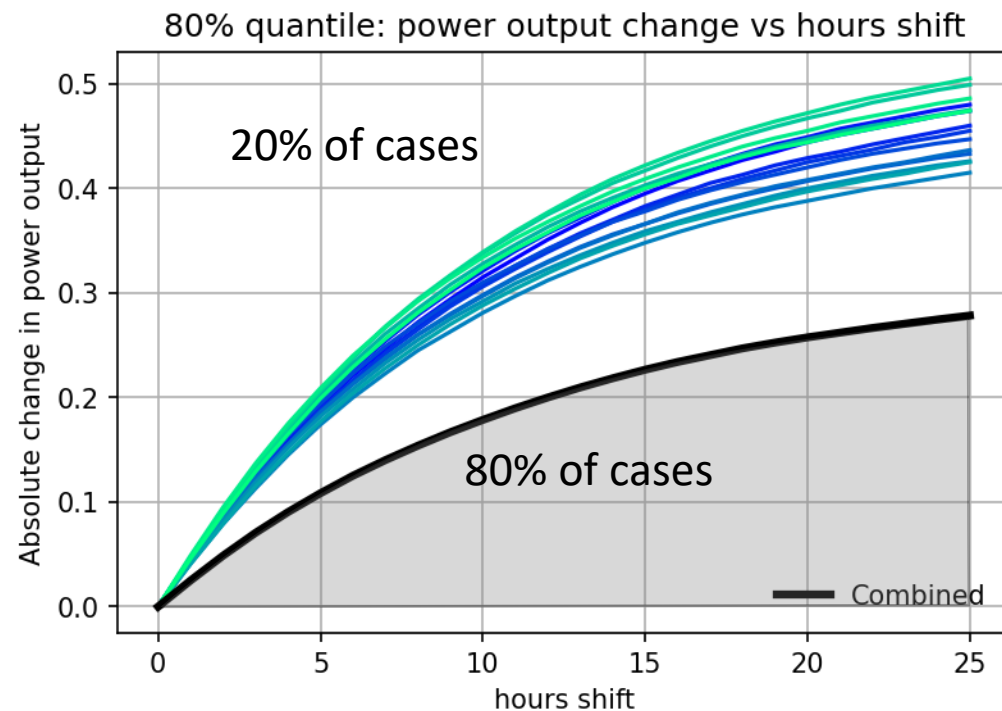




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Short-time variation (power ramping)

How much does the power output change from one hour to the next few hours?



Individual wind farms

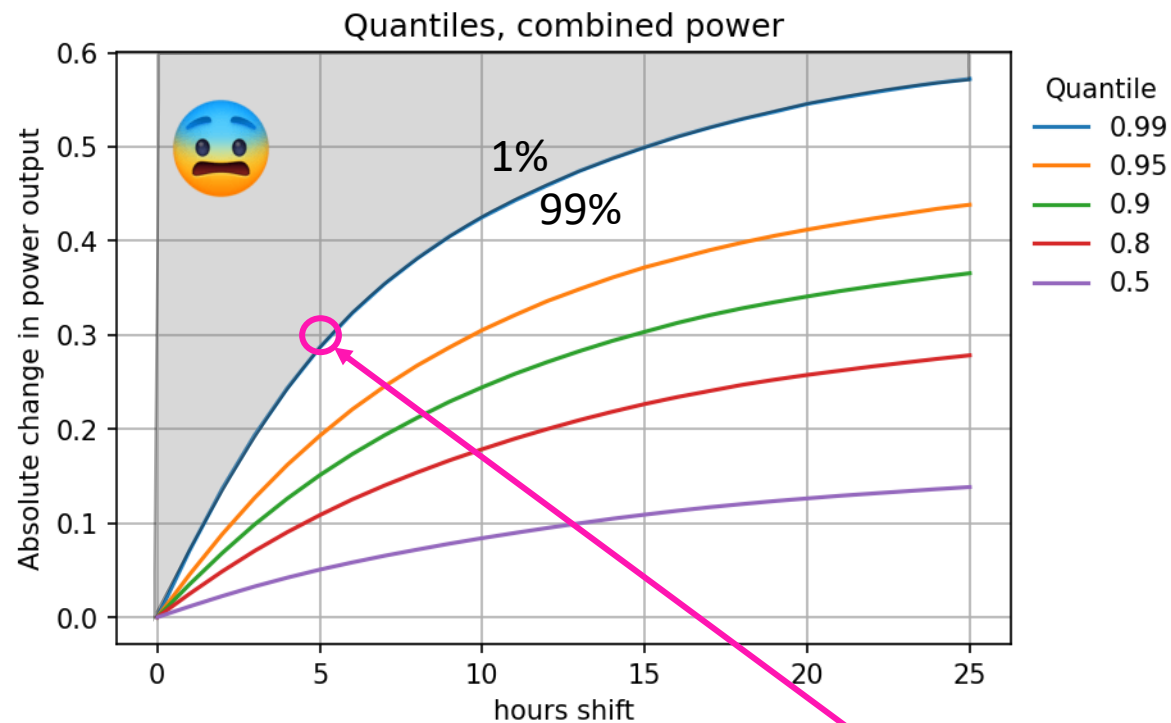
↓ Smoothing

Combined output



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More on ramps (combined power)



>30% (9 GW) change during 5 hours
Occurs in less than 1% of the hours

Very large ramps within a few hours are not common, but do occur

Must be compensated for, e.g.

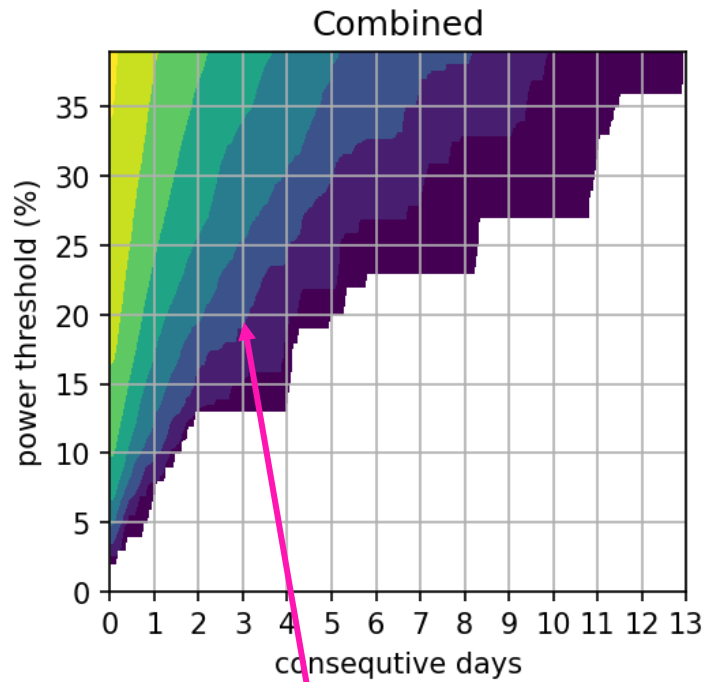
- ramp control
- other generation or flexible resources

Not possible to reliably identify “worst case” scenario with our simplified approach.

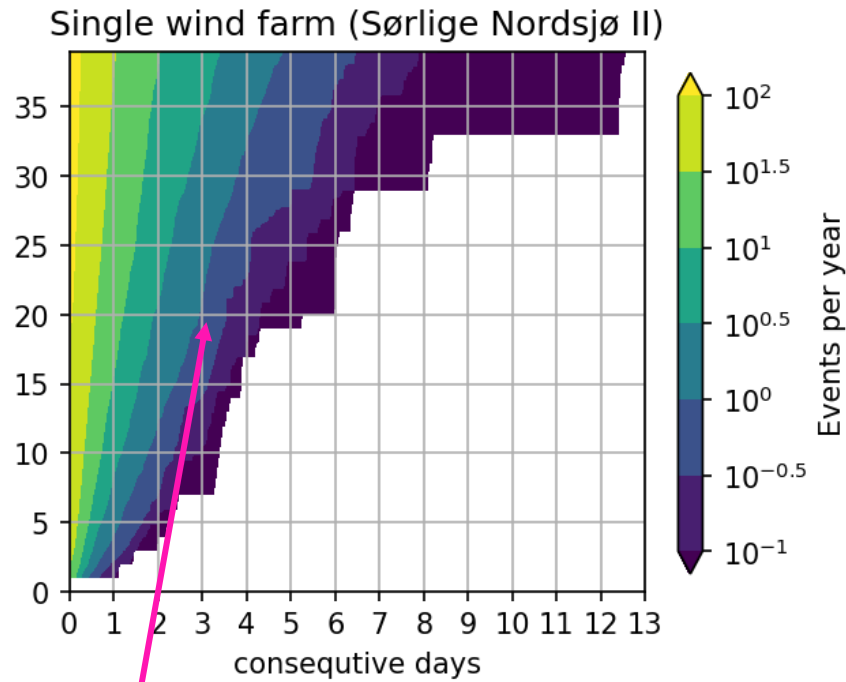


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How often will there be no wind power?

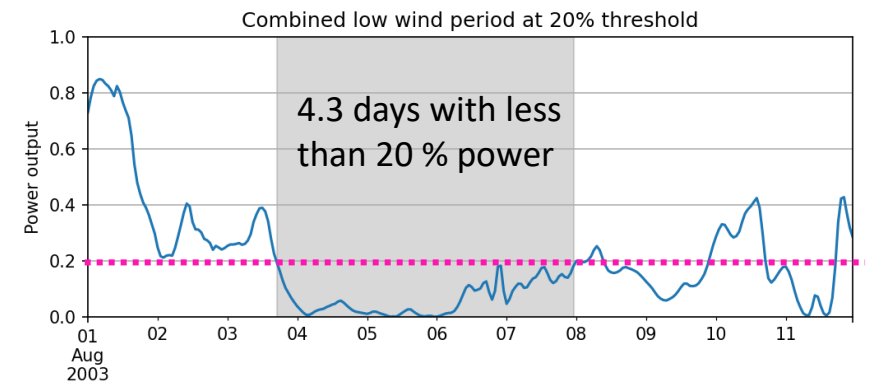


Example: Power < 20 %
for 3 days or more:
0.3 event per year



1 event per year

- Several consecutive days of little wind do occur
- Geographical smoothing makes it less frequent for combined power





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Thank you for your attention

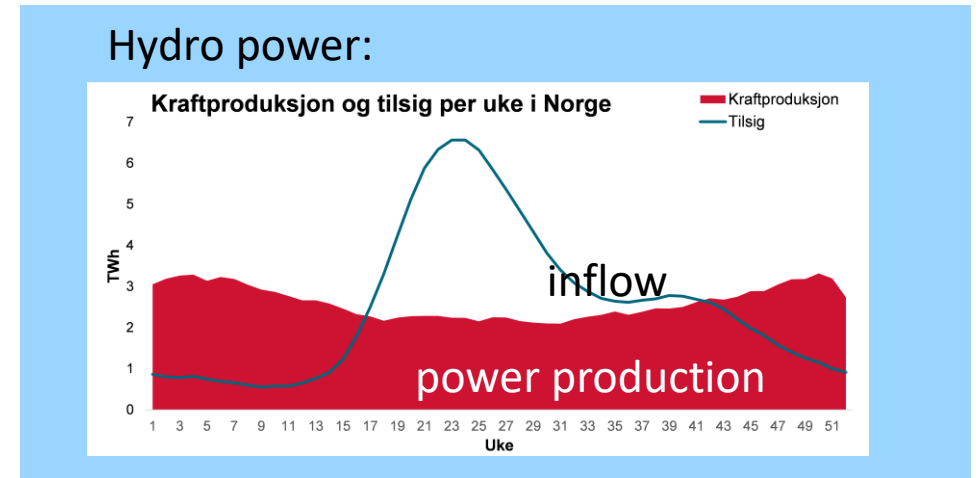
Correlation coefficients – hourly time series

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	D	H	B
0	1.000000	0.891679	0.660122	0.317546	0.290172	0.251498	0.134178	0.146067	0.122021	0.125346	0.083641	0.063037	0.046833	0.043950	0.056034	0.580686	0.726229	0.421194
1	0.891679	1.000000	0.732527	0.401377	0.369335	0.329114	0.158844	0.158420	0.136821	0.141586	0.093945	0.071178	0.049915	0.045444	0.054194	0.589770	0.576323	0.339743
2	0.660122	0.732527	1.000000	0.604587	0.558783	0.487500	0.261657	0.269053	0.238859	0.239675	0.154039	0.115103	0.071268	0.053148	0.057172	0.394220	0.455865	0.261509
3	0.317546	0.401377	0.604587	1.000000	0.993905	0.886574	0.562044	0.428159	0.404047	0.402506	0.297771	0.244345	0.177039	0.141350	0.123837	0.251511	0.209553	0.111582
4	0.290172	0.369335	0.558783	0.993905	1.000000	0.895698	0.597946	0.444130	0.418668	0.416999	0.311861	0.257796	0.189194	0.152404	0.131547	0.231768	0.191953	0.101907
5	0.251498	0.329114	0.487500	0.886574	0.895698	1.000000	0.601059	0.389797	0.365593	0.354122	0.260254	0.212012	0.151453	0.120212	0.103310	0.196472	0.160737	0.090911
6	0.134178	0.158844	0.261657	0.562044	0.597946	0.601059	1.000000	0.668535	0.551306	0.517230	0.384454	0.327438	0.251806	0.214676	0.170437	0.079176	0.116840	0.095714
7	0.146067	0.158420	0.269053	0.428159	0.444130	0.389797	0.668535	1.000000	0.825533	0.782483	0.499218	0.400088	0.295411	0.242797	0.193653	0.083925	0.129530	0.108161
8	0.122021	0.136821	0.238859	0.404047	0.418668	0.365593	0.551306	0.825533	1.000000	0.961113	0.672490	0.530499	0.381699	0.304863	0.233674	0.080027	0.102058	0.075364
9	0.125346	0.141586	0.239675	0.402506	0.416999	0.354122	0.517230	0.782483	0.961113	1.000000	0.732327	0.588658	0.434186	0.353276	0.272366	0.088120	0.103240	0.076963
10	0.083641	0.093945	0.154039	0.297771	0.311861	0.260254	0.384454	0.499218	0.672490	0.732327	1.000000	0.906870	0.691846	0.560312	0.397208	0.058877	0.069064	0.052659
11	0.063037	0.071178	0.115103	0.244345	0.257796	0.212012	0.327438	0.400088	0.530499	0.588658	0.906870	1.000000	0.857918	0.714091	0.491844	0.043110	0.052353	0.044299
12	0.046833	0.049915	0.071268	0.177039	0.189194	0.151453	0.251806	0.295411	0.381699	0.434186	0.691846	0.857918	1.000000	0.924696	0.668989	0.034735	0.038787	0.037243
13	0.043950	0.045444	0.053148	0.141350	0.152404	0.120212	0.214676	0.242797	0.304863	0.353276	0.560312	0.714091	0.924696	1.000000	0.820897	0.033269	0.038156	0.043093
14	0.056034	0.054194	0.057172	0.123837	0.131547	0.103310	0.170437	0.193653	0.233674	0.272366	0.397208	0.491844	0.668989	0.820897	1.000000	0.048624	0.058707	0.065361
D	0.580686	0.589770	0.394220	0.251511	0.231768	0.196472	0.079176	0.083925	0.080027	0.088120	0.058877	0.043110	0.034735	0.033269	0.048624	1.000000	0.495449	0.293420
H	0.726229	0.576323	0.455865	0.209553	0.191953	0.160737	0.116840	0.129530	0.102058	0.103240	0.069064	0.052353	0.038787	0.038156	0.058707	0.495449	1.000000	0.636377
B	0.421194	0.339743	0.261509	0.111582	0.101907	0.090911	0.095714	0.108161	0.075364	0.076963	0.052659	0.044299	0.037243	0.043093	0.065361	0.293420	0.636377	1.000000



Seasonal variation Today – hydro power

For comparison



Water **reservoirs** compensate for the mismatch in power demand (production) and water inflow