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Wake losses and power production at the Vestavind F offshore wind farm

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AEP prediction and wake losses at Norwegian offshore sites by NVE

- ERA5 re-analysis wind data
- IEA 15 MW refence turbine
- 17.5% losses (wake and downtime) by default
- Capacity factor C_F = 50.1%

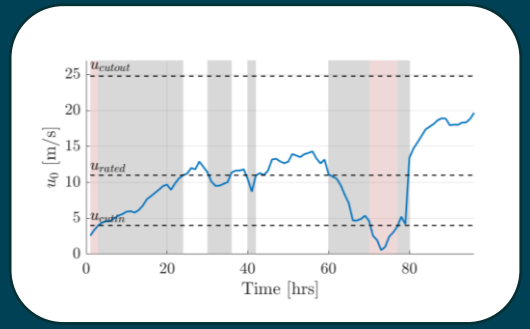
Tabell: Oppsummering av produksjonsdata for de identifiserte områdene.

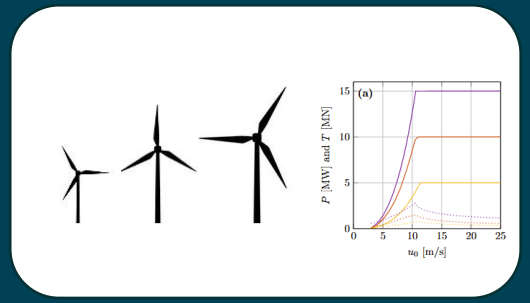
Område	Gjennomsnittlig vindhastighet (m/s)	Brukstid med tap (timer)	Årlig produksjon med tap (TWh)	Kapasitetsfaktor med tap (%)	Brukstid uten tap (timer)	Årlig produksjon uten tap(TWh)	Kapasitetsfaktor uten tap (%)	Strømforbruk antall husstander
Nordavind A	9,6	4344	4,34	49,6	5278	5,28	60,3	271478
Nordavind B	9,8	4400	4,40	50,2	5343	5,34	61,0	274991
Nordavind C	9,8	4278	4,28	48,8	5184	5,18	59,2	267197
Nordavind D	9,8	4275	4,28	48,8	5180	5,18	59,1	267369
Nordvest A	9,9	4340	4,34	49,5	5237	5,24	59,8	271244
Nordvest B	9,9	4233	4,23	48,3	5121	5,12	58,5	264550
Nordvest C	9,9	4115	4,11	47,0	4971	4,97	56,7	257164
Vestavind A	10,7	4491	4,49	51,3	5425	5,43	61,9	280666
Vestavind B	10,3	4348	4,35	49,6	5266	5,27	60,1	271765
Vestavind E	10,6	4579	4,58	52,3	5545	5,54	63,3	286200
Vestavind F	10,2	4386	4,39	50,1	5318	5,32	60,7	274108
Sørvest A	10,8	4777	4,78	54,5	5777	5,78	65,9	298574
Sørvest B	10,6	4754	4,75	54,3	5746	5,75	65,6	297113
Sørvest C	10,7	4826	4,83	55,1	5835	5,83	66,6	301647
Sørvest D	10,6	4772	4,77	54,5	5771	5,77	65,9	298220
Sørvest E	10,9	4910	4,91	56,1	5935	5,94	67,8	306874
Sørvest F	10,7	4901	4,90	55,9	5924	5,92	67,6	306310
Sønnavind A	10,9	4952	4,95	56,5	5995	6,00	68,4	309481

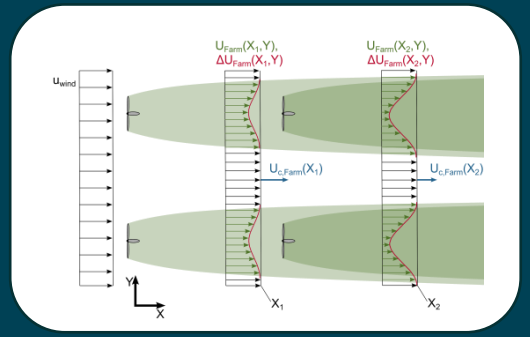
[NVE, 2023]

Methodology

- Input wind data: NORA3
- Wind turbine models & farm layout
- Wake modelling in *Qwyn*

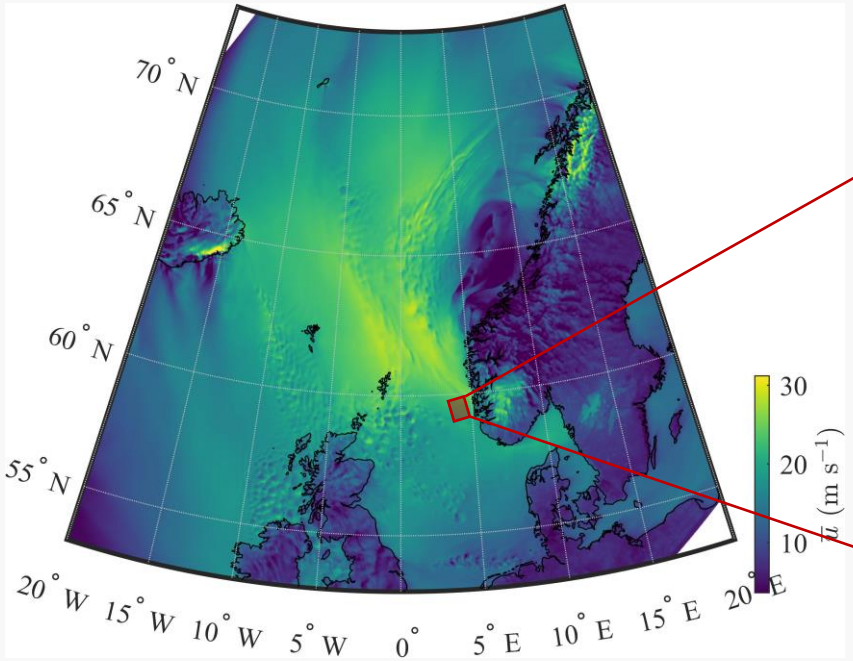




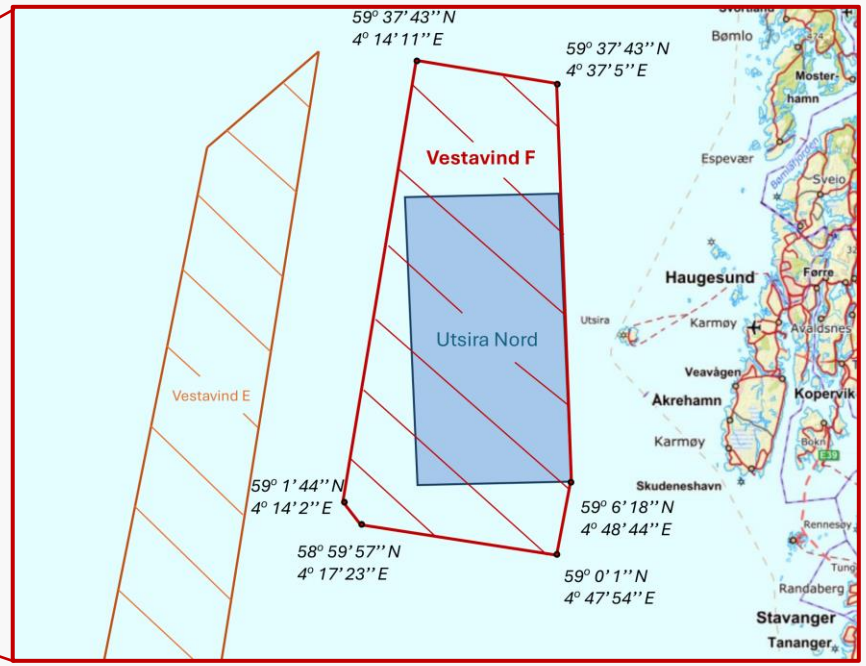


NORA 3

- Temporal resolution: 1 hour
- Spatial resolution: 3 km
- Utsira Nord: 1010 km^2



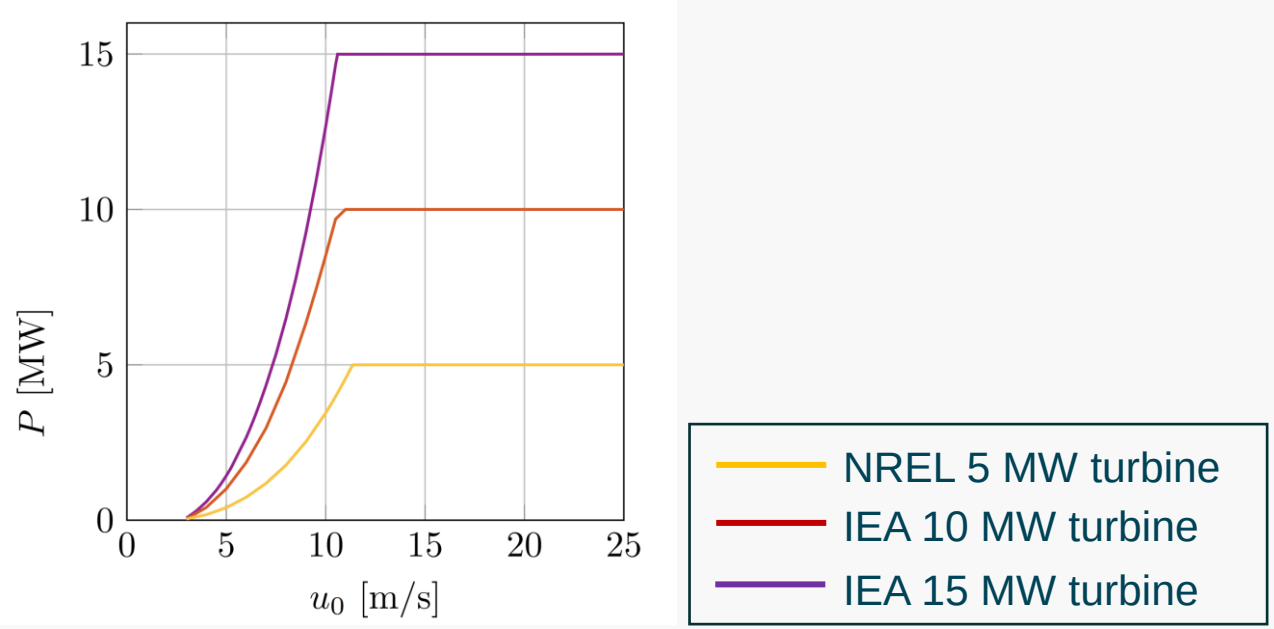
Average wind speed in the northern sea [Cheynet, 2025]



Vestavind F and Utsira Nord area [Vestavind F, 2023]

Wind turbine models

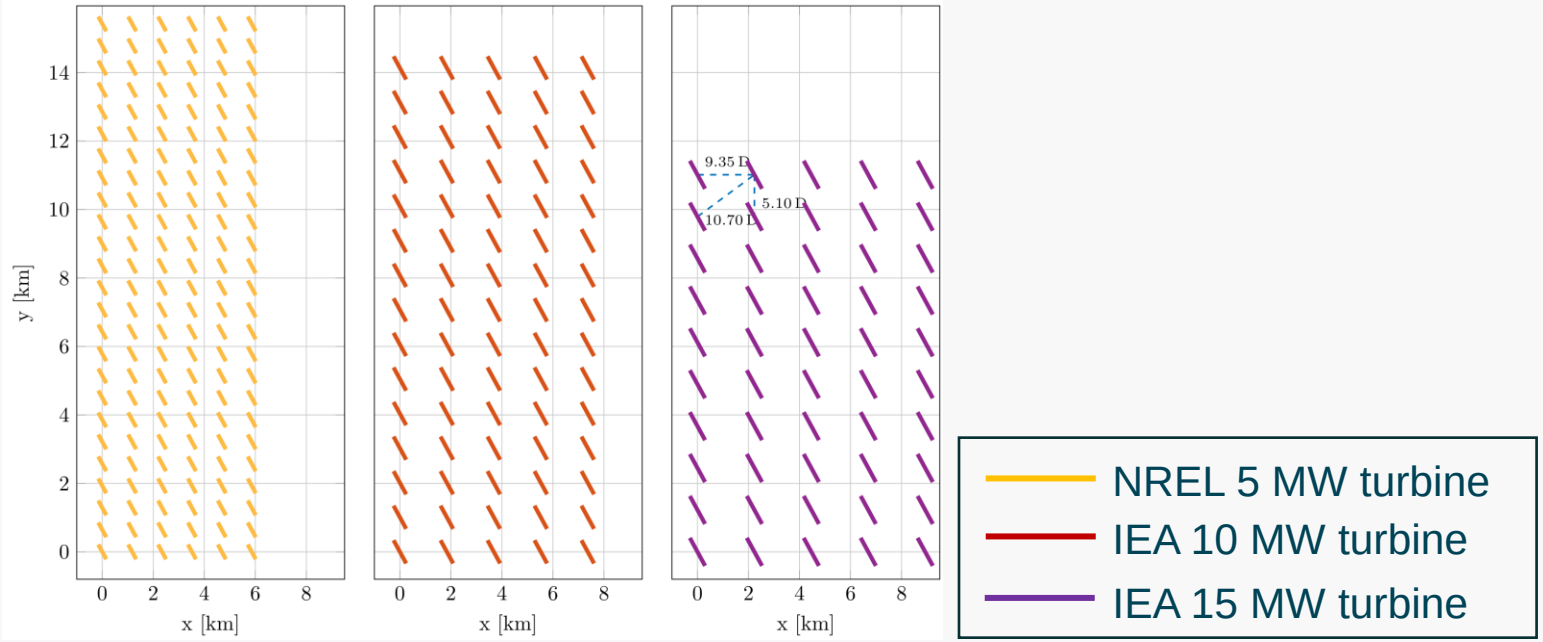
		NREL 5 MW	IEA 10 MW	IEA 15 MW
Rotor diameter	D [m]	126	198	240
Cut-in speed	u_{cut-in} [m/s]	3.0	4.0	3.0
Cut-out speed	$u_{cut-out}$ [m/s]	25.0	25.0	25.0
Rated speed	u_{rated} [m/s]	11.4	11.0	10.6



Power curves

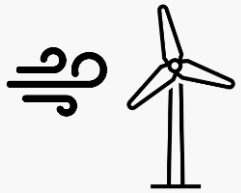
Wind farm layout

		NREL 5 MW	IEA 10 MW	IEA 15 MW
Total capacity	[MW]	750	750	750
Number of turbines	[−]			
Total area	$[km^2]$			
Capacity density	$[\mathrm{MW}/km^2]$			



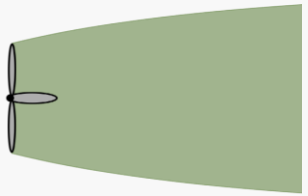
Farm Layouts for Utsira Nord

Wake modelling methodology: *Qwyn*



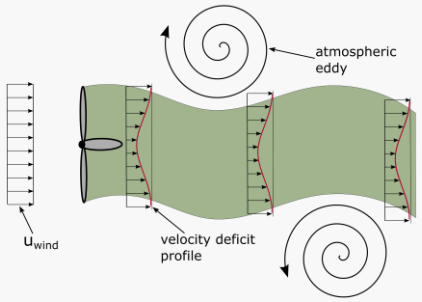
ambient &
turbine data

modelling



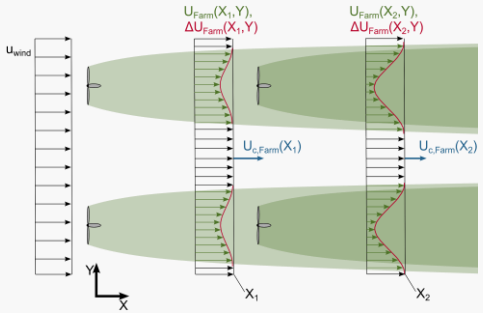
wind speed & turbulence
in wake region
[Ishihara, 2018]

correcting



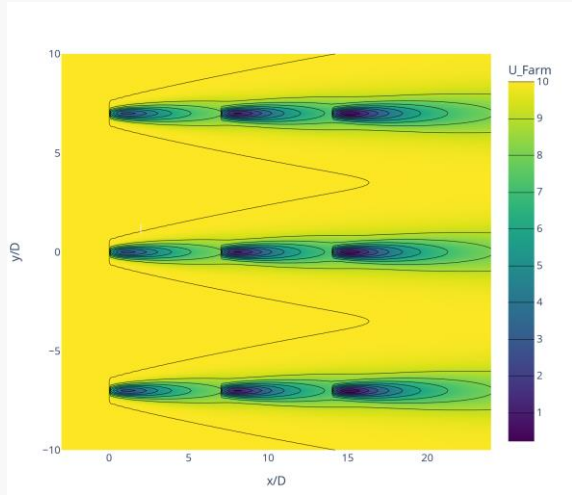
wake meandering
[Braunbehrens, 2019]

wake mixing



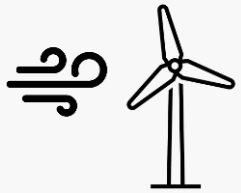
superimposed result
in a wind farm
[Zong, 2020]

result

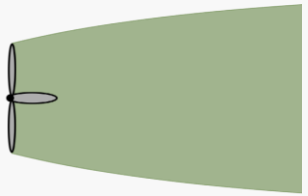


AEP

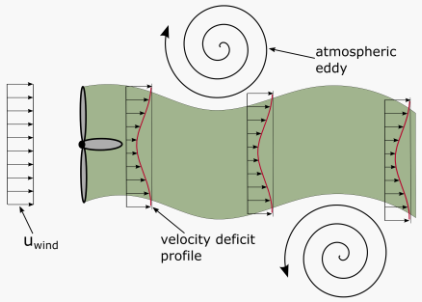
Wake modelling methodology: *Qwyn*



modelling



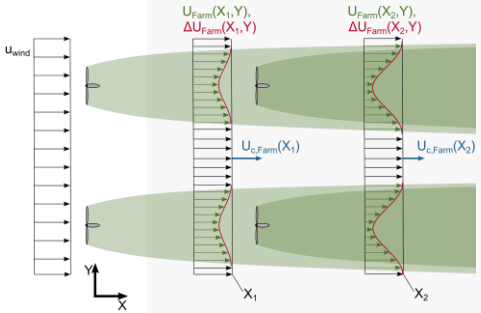
correcting



ambient & turbine data

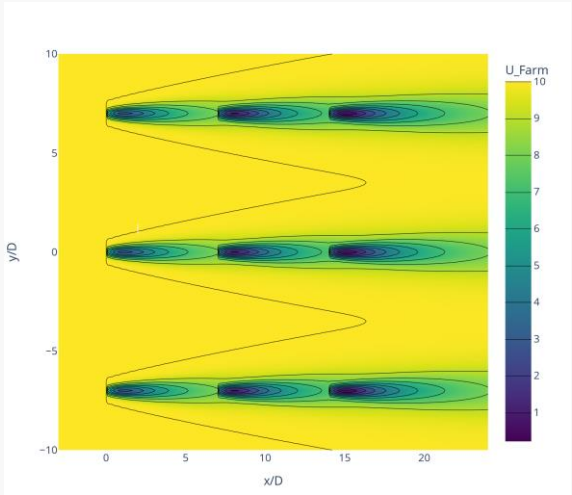
wind speed & turbulence in wake region
[Ishihara, 2018]

wake meandering
[Braunbehrens, 2019]

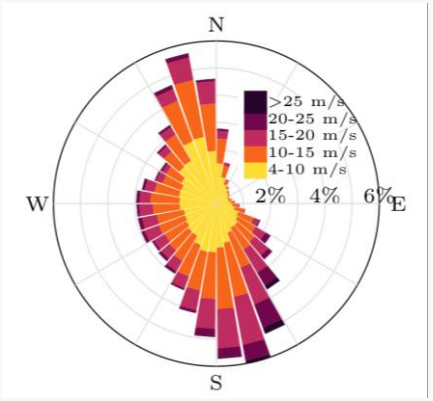


superimposed result in a wind farm
[Zong, 2020]

result

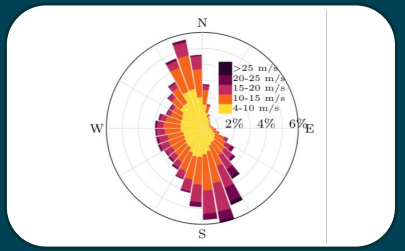


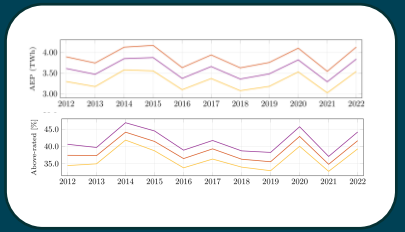
AEP

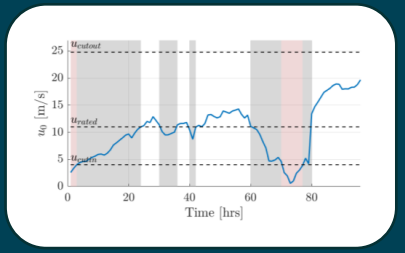


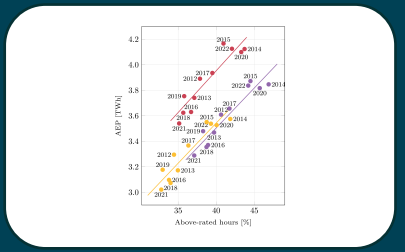
Results

- Wind Statistics Vestavind F
- AEP & Wake losses
- Influence of Below- and Above-rated Winds on Wake Losses
- Correlations & Influence factors



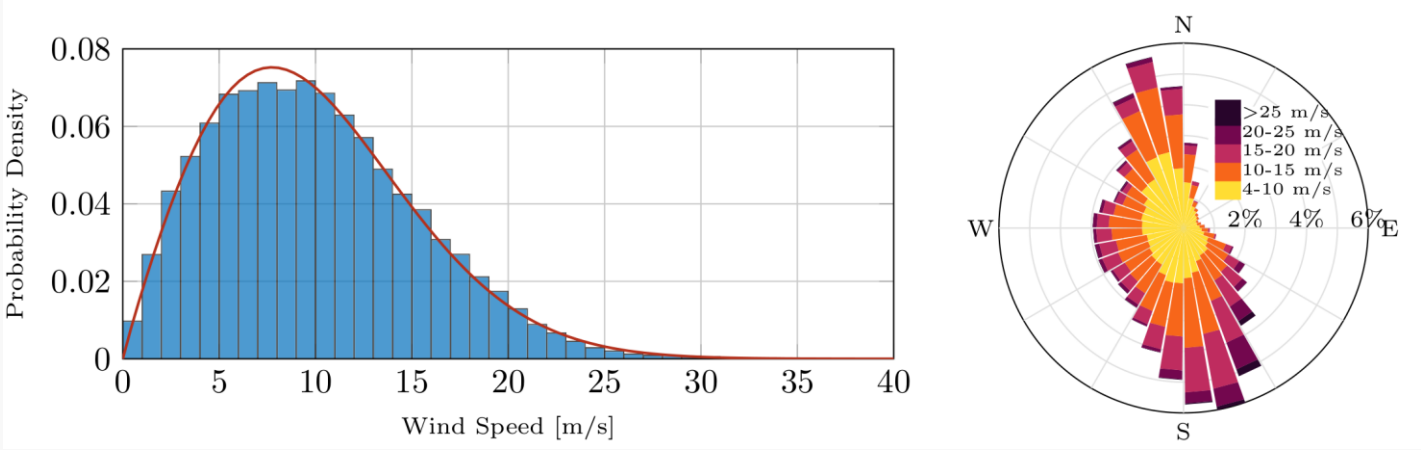




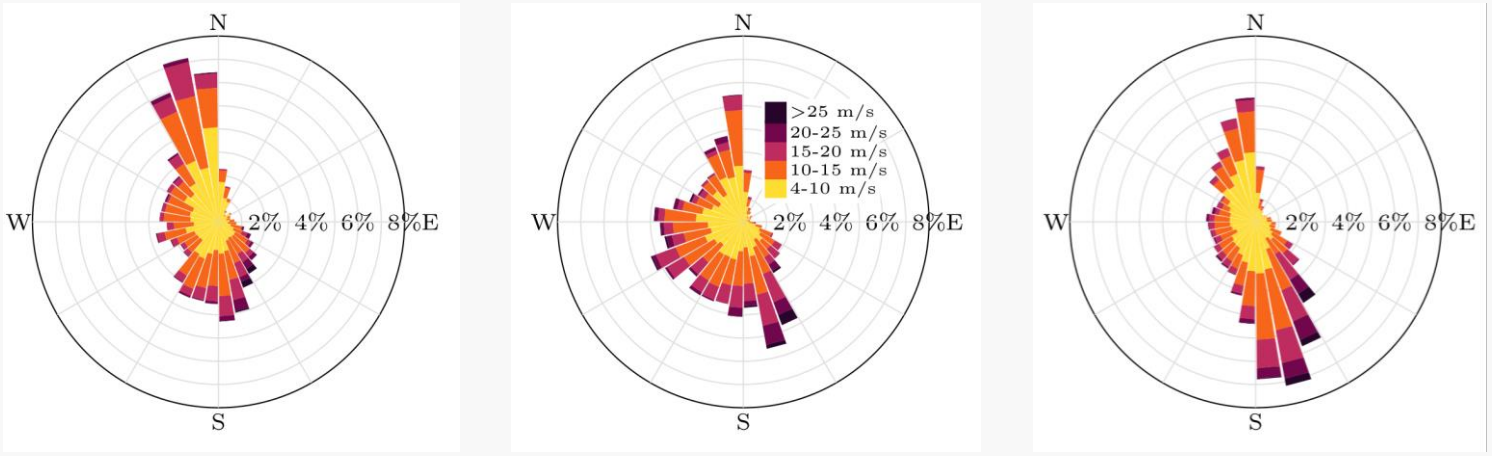


Wind Statistics Vestavind F

- Average, 2012-2022

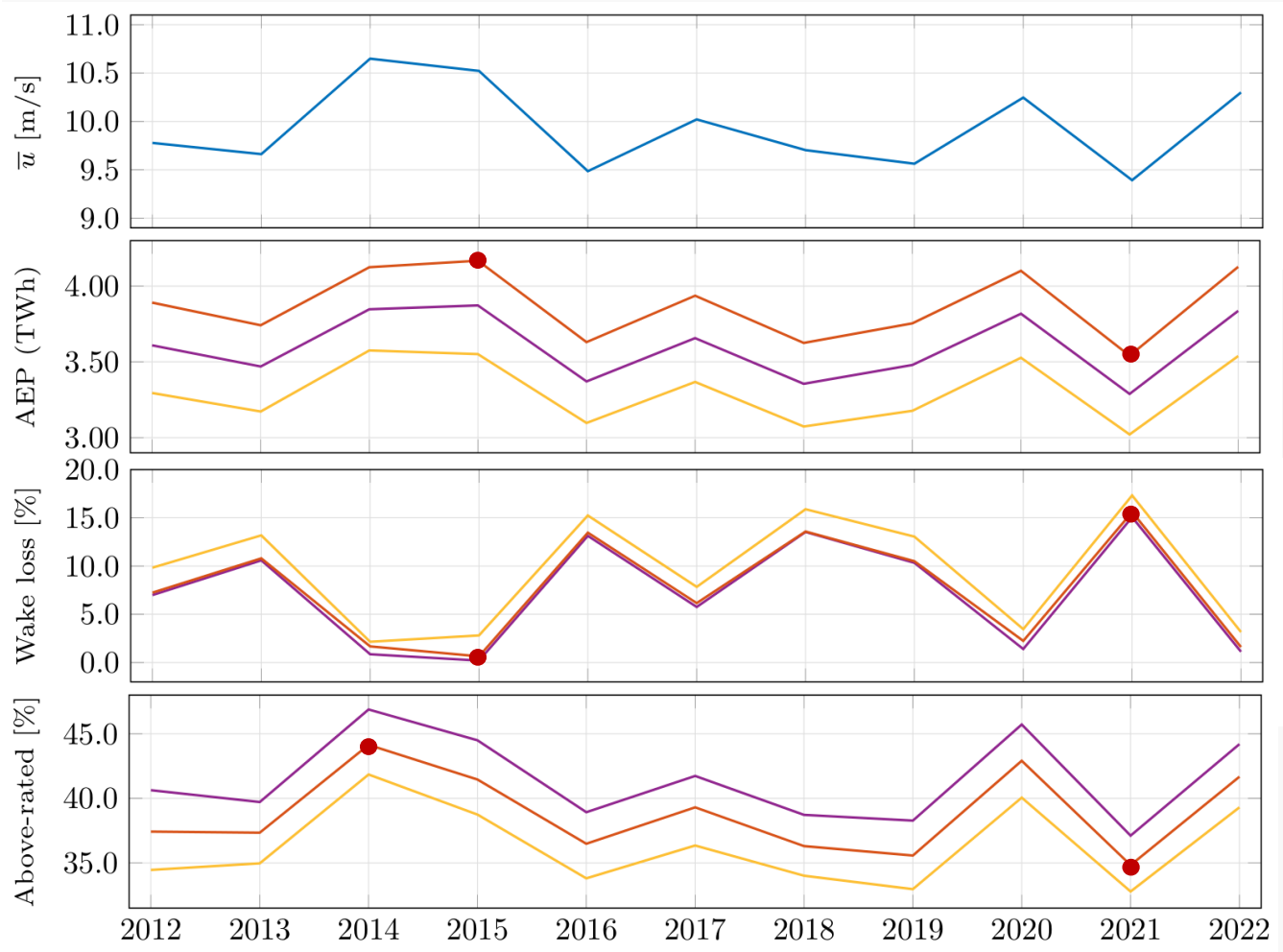


- Year by year



2012 2015 2018

Annual Energy Production and Wake Losses



Average wind speed
NREL 5 MW farm
IEA 10 MW farm
IEA 15 MW farm

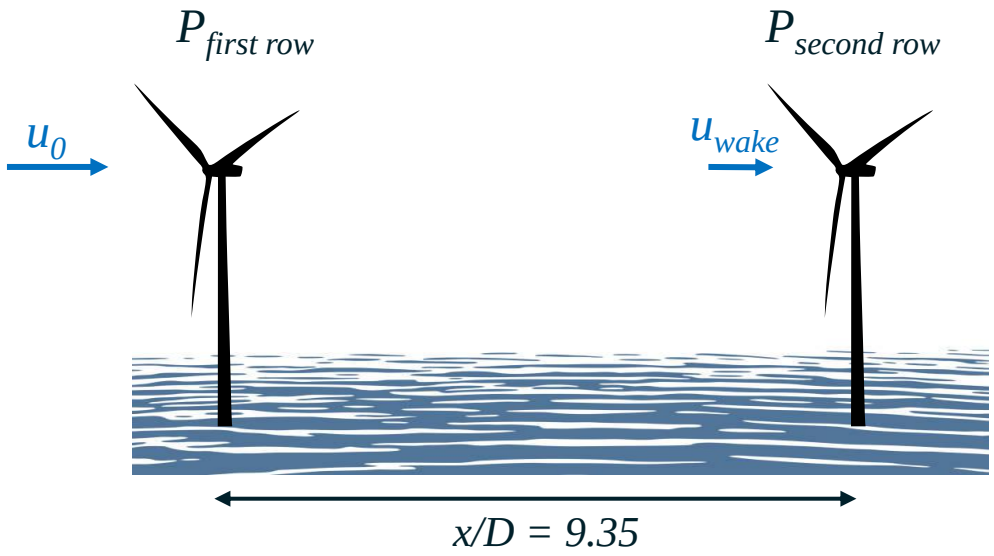
Annual Energy Production:
AEP_{min} = 3.54 TWh (2021)
AEP_{max} = 4.17 TWh (2015)

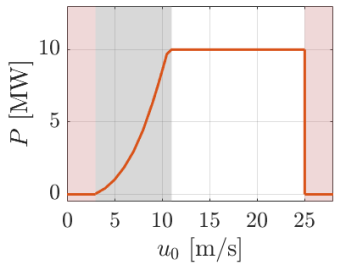
Wake Losses:
WL_{min} = 0.53 % (2015)
WL_{max} = 15.60 % (2021)

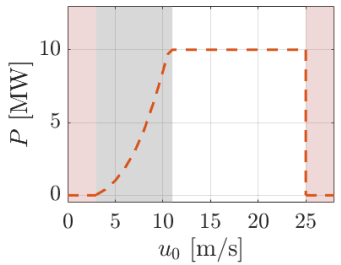
Hours of *above-rated* operation:
$T(u > u_{rated})$ = 44 % (2014)
$T(u > u_{rated})$ = 35 % (2021)

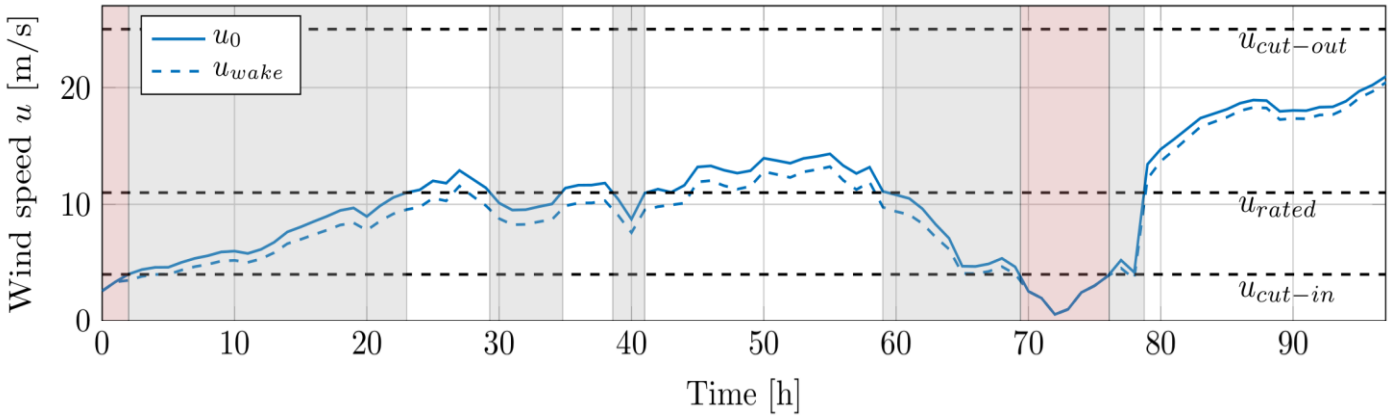
Influence of Below- and Above-rated Winds on Wake Losses

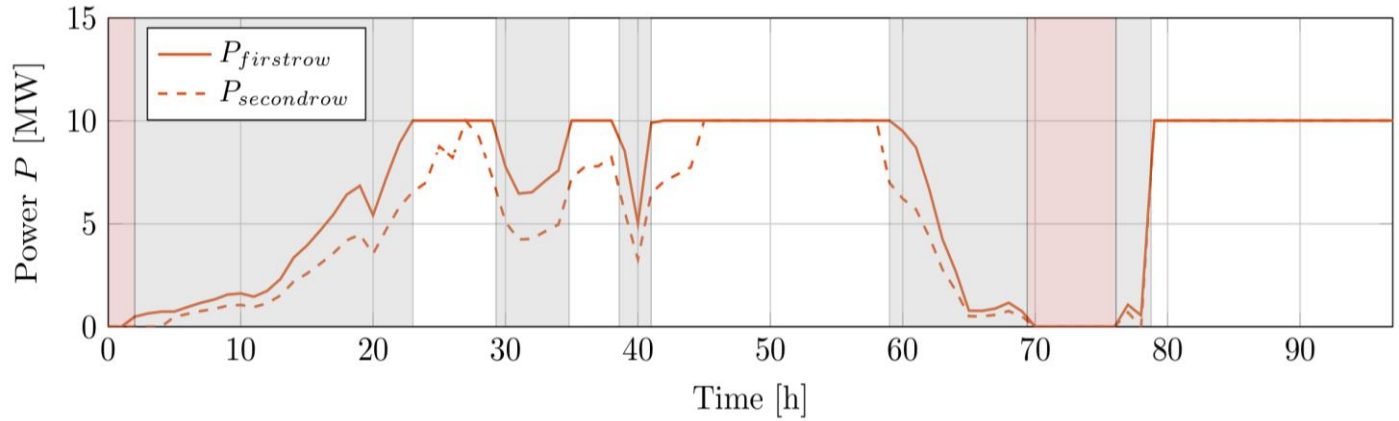
› Isolating two in-line IEA 10 MW turbines from the farm for a period of 4 days…



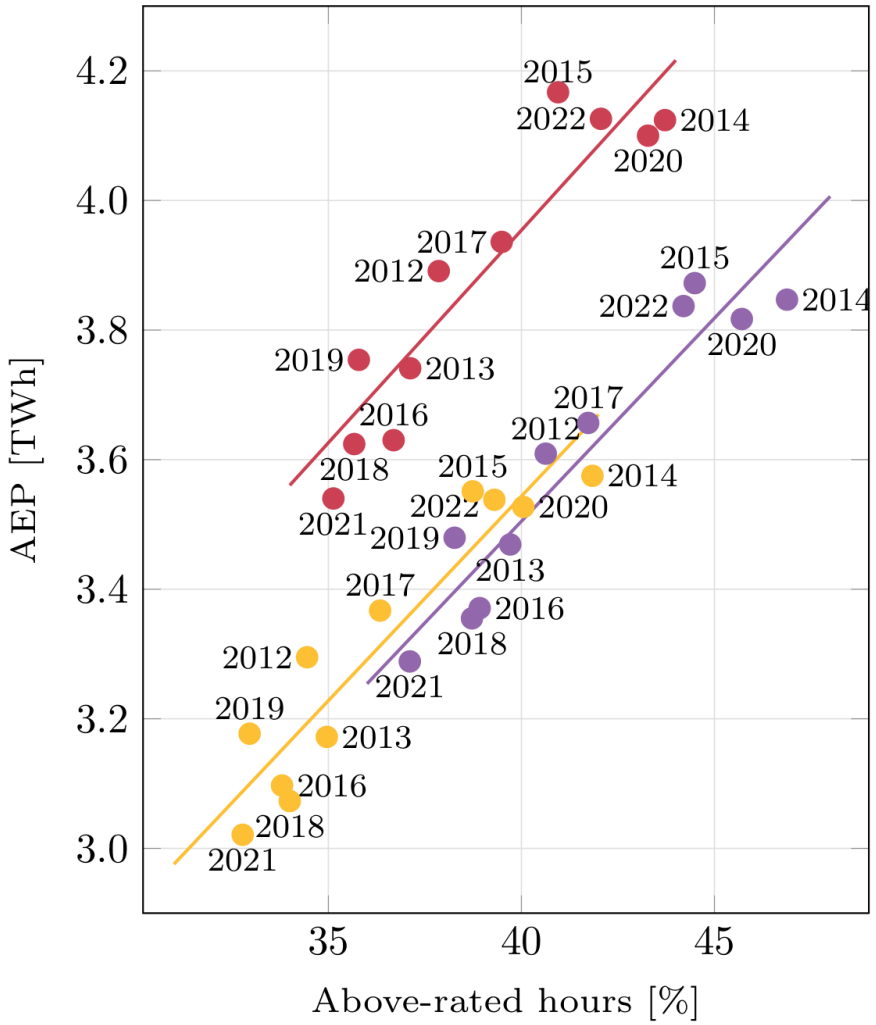


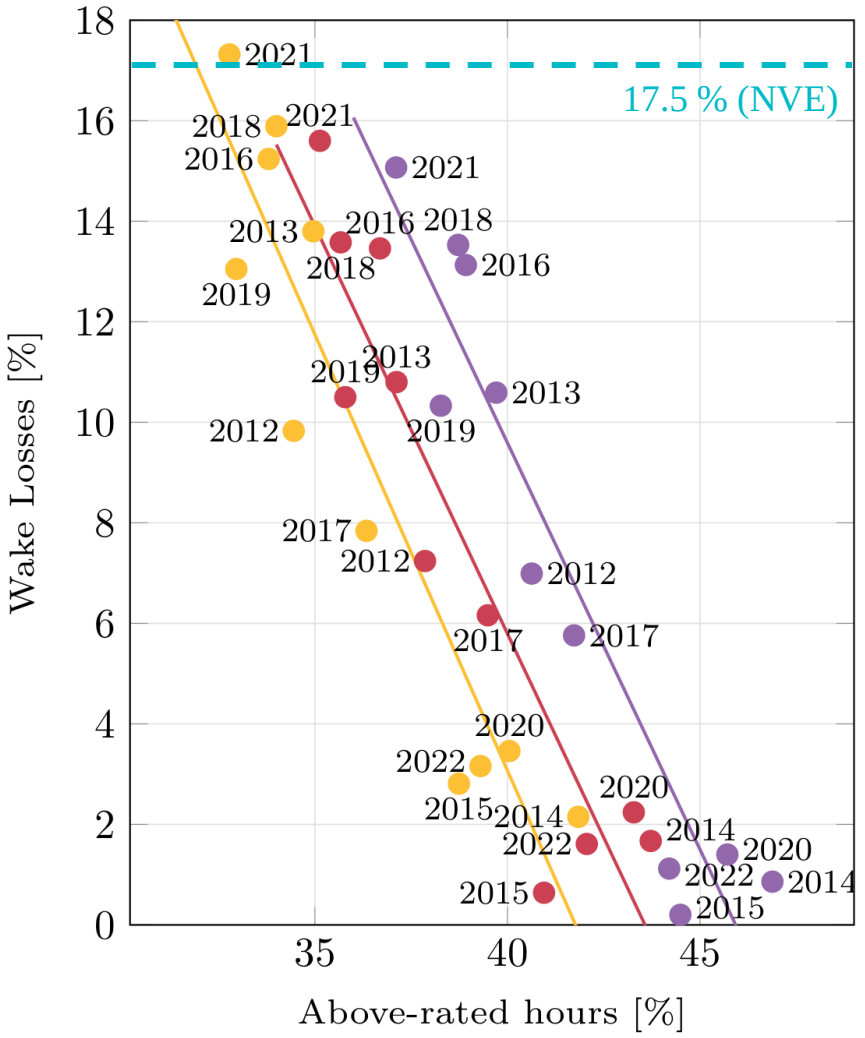


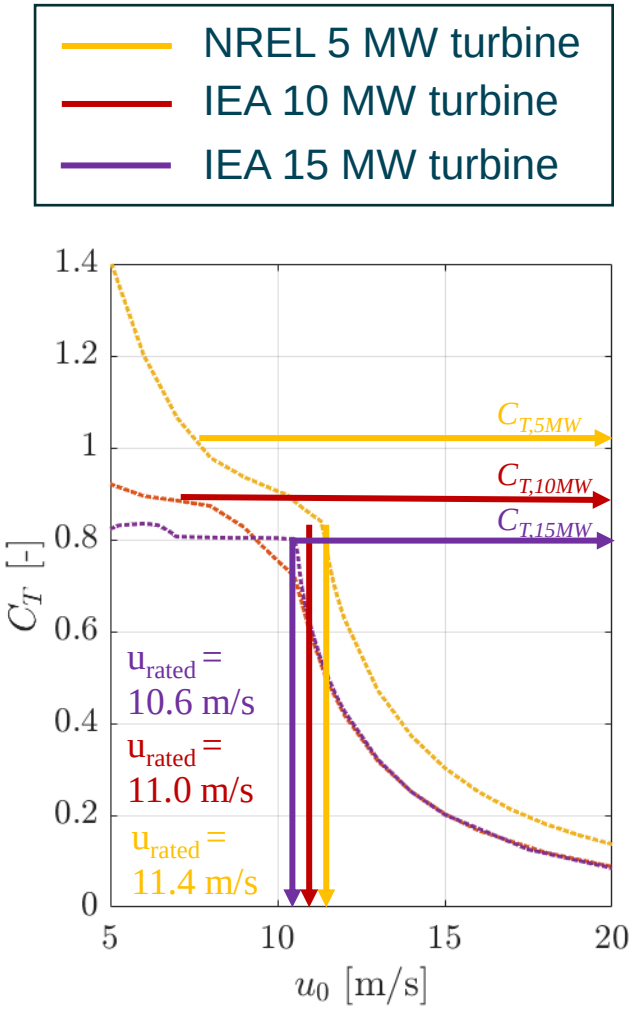




Correlations & Influence factors







Conclusions

- *Wake losses* vary between 0.53% and of 15.60% from year to year.
- *Wake losses* correlate inversely to the *average wind speeds* and the *AEP.*
- The turbines' *rated wind speeds* and *thrust coefficients* are main contributors.
- NVE's estimate of 17.50% losses is rather conservative.
- *Several years/decades of wind data* should be considered when calculating a wind farm's *wake losses*.

References

[Cheynet, 2025] E. Cheynet (2025). Gridded NORA3 data: automated and remote data extraction (*https://github.com/ECheynet/NORA3/releases/tag/v1.5*) GitHub. Retrieved January 3, 2025.

[NVE, 2023] Norwegian Water Resources and Energy Directorate (2023). Calculation of power production for the identified areas (*https://veiledere.nve.no/havvind/identifisering-av-utredningsomrader-for-havvind/metode-og-vurderinger/beregning-av-kraftproduksjon*). Retrieved December 10, 2024.

[Vestavind F, 2023] Norwegian Water Resources and Energy Directorate. Vestavind F (*https://veiledere.nve.no/havvind/identifisering-av-utredningsomrader-for-havvind/nye-omrader-for-havvind/vestavind-f-inkl-utsira-nord/*). Retrieved January 3, 2025.