

ERA 5 calibration to Elexon power

S. Gomez¹

¹School of Mathematics, University of Edinburgh

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Calibration to power

Updates

- Curtailment data to obtain potential generation
- Outage data to exclude periods where capacity is constrained
- Updated power curve comparison to data
- ERA 5 wind speed conversion to power

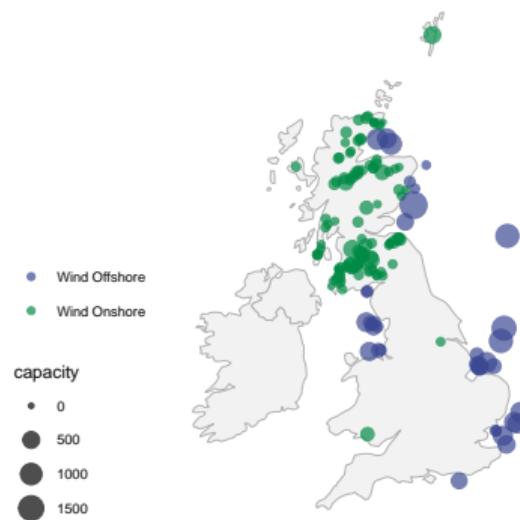
ERA5 vs Elexon generation

Calibrate a ERA5 driven estimate to actual observed output accounting for spatiotemporal properties.

ERA5 at wind farms



Elexon wind farms map (2025)

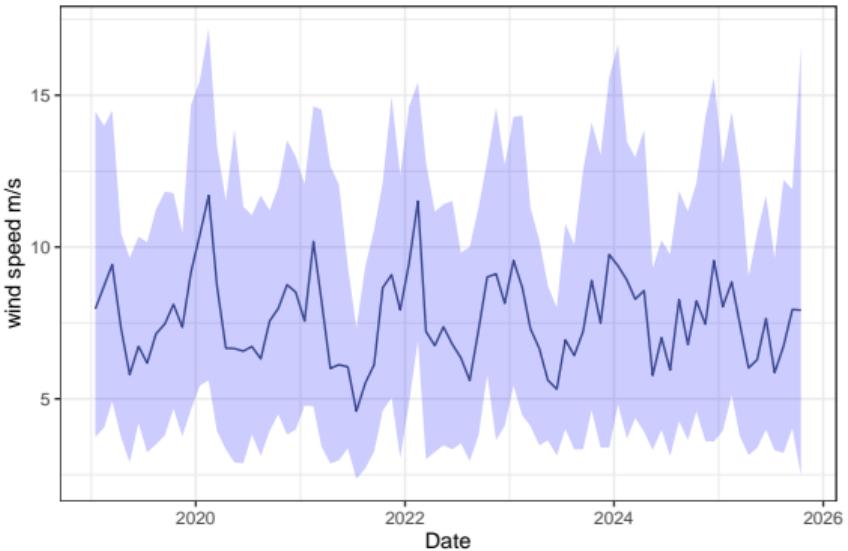


ERA5

Characteristics

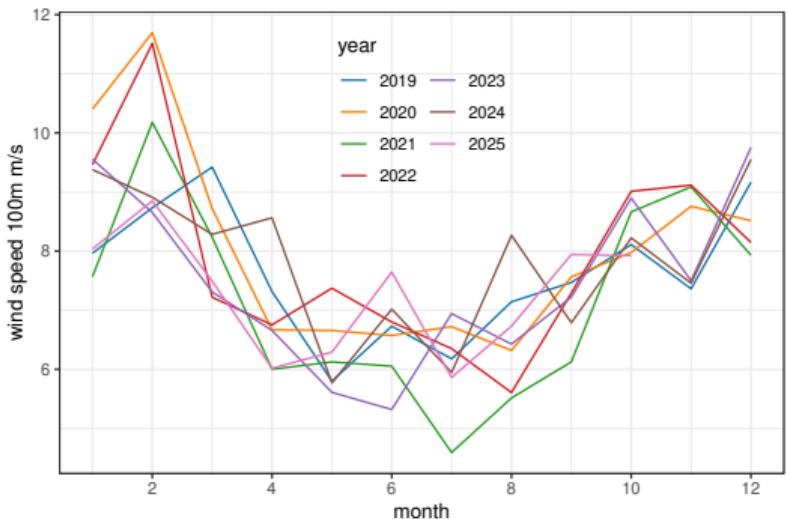
- 5th generation of ECMWF's global reanalysis
- Spatial resolution $0.25^\circ \times 0.25^\circ$ (31km \times 31 km at equator)
- Hourly temporal resolution
- Heights: 10m, 100m

Average monthly wind speed and 90 CI

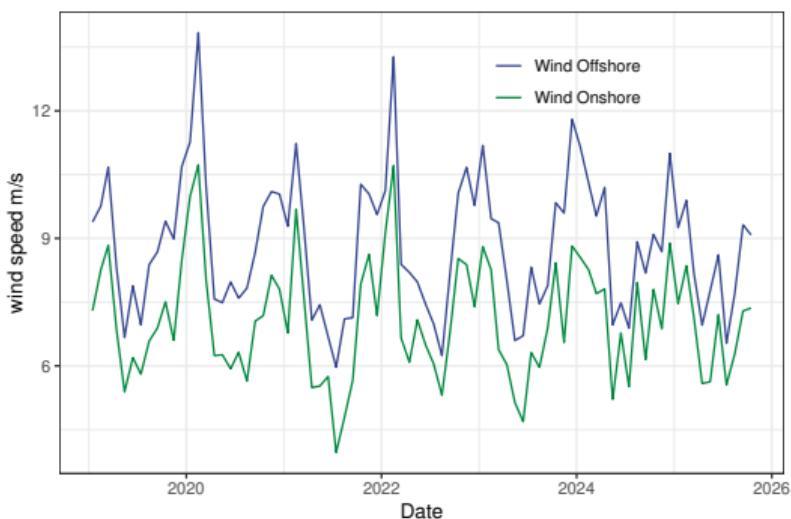


ERA5 series

Wind speed seasonality



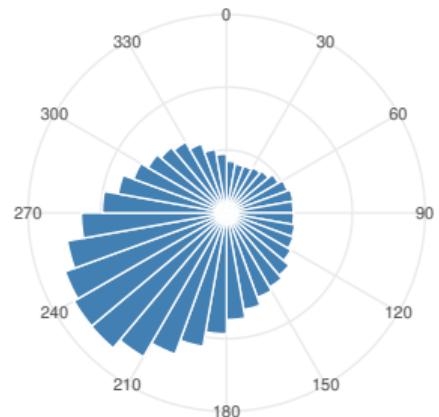
Wind speed by location type



ERA5 wind direction at wind farms

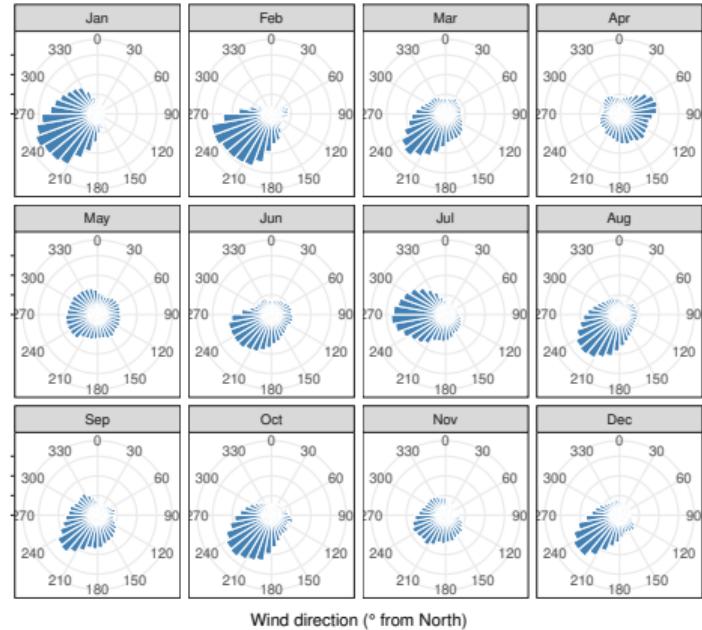
Wind direction frequency

Radial Histogram of Wind Direction (100 m)



Seasonal patterns

Radial Histogram of Wind Direction (100 m)

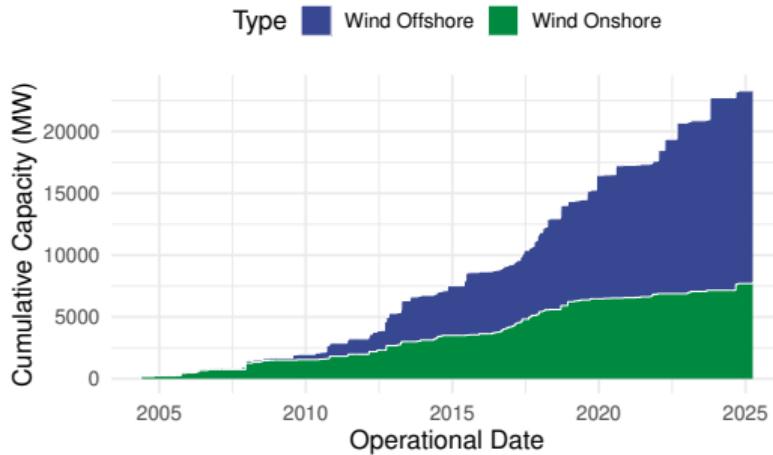


Elexon data

BMU wind data

- 150 wind farms split in over 216 units
- Total capacity: 27 GW
- Half hourly resolution
- Records starting in 2019
- Curtailment and outage data available
- Location / turbine data unavailable

Wind installed capacity

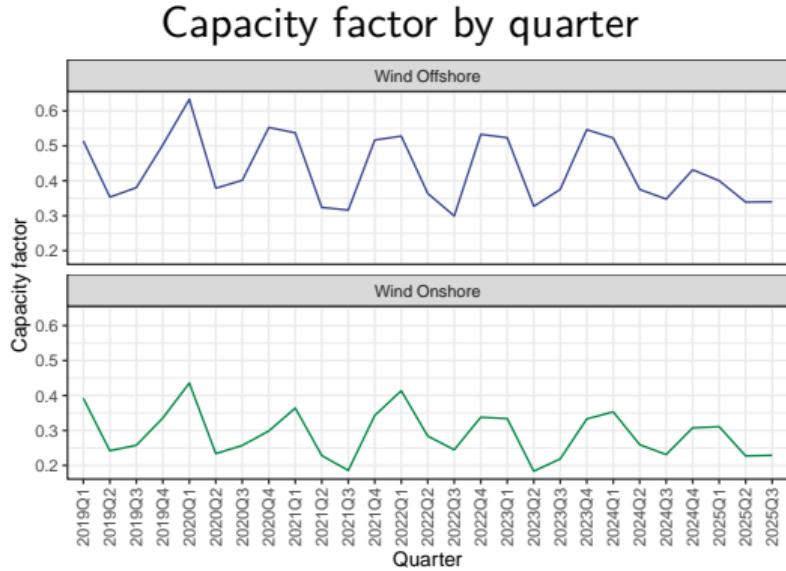
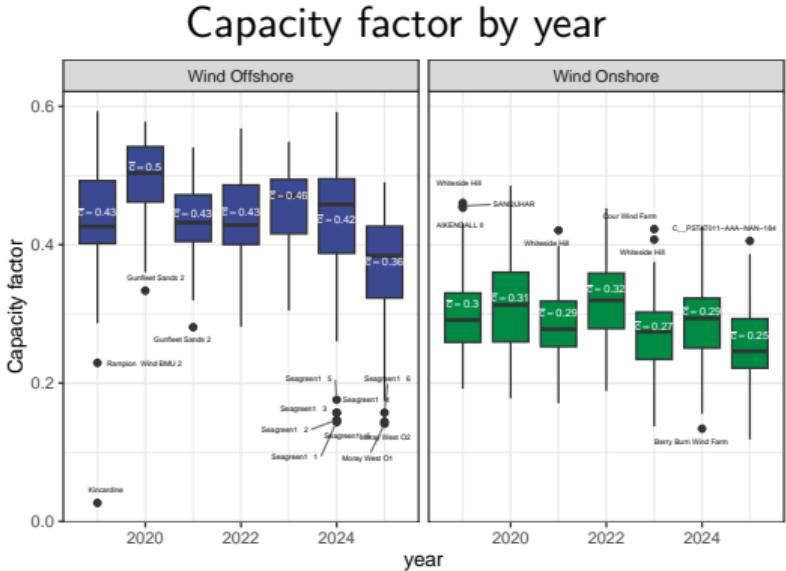


BMU wind data

BMU wind generation (2024)

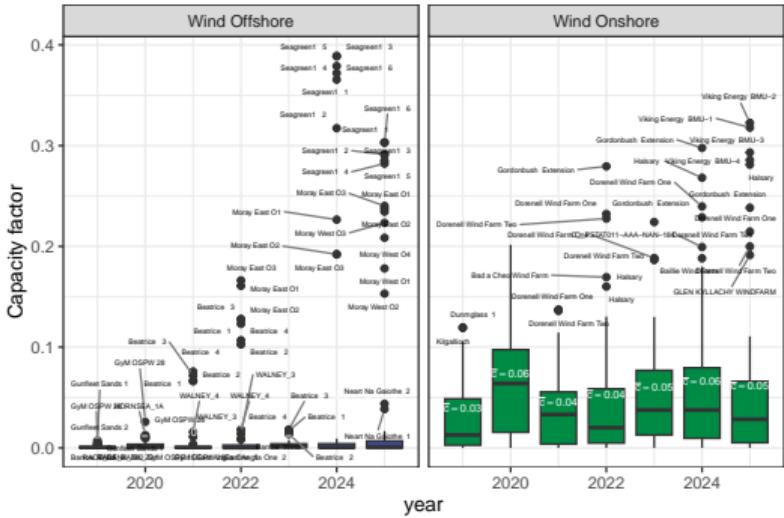
Type	Generation (GWh)	Curtailment	Potential	Capacity (MW)	Number of BMUs	CF	PF
Wind Offshore	46,907	4,902	51,810	15,563	80	0.42	0.47
Wind Onshore	16,254	3,363	19,617	7,860	123	0.29	0.34
Total	63,162	8,266	71,427	23,423	203	0.37	0.42

Capacity factor through time

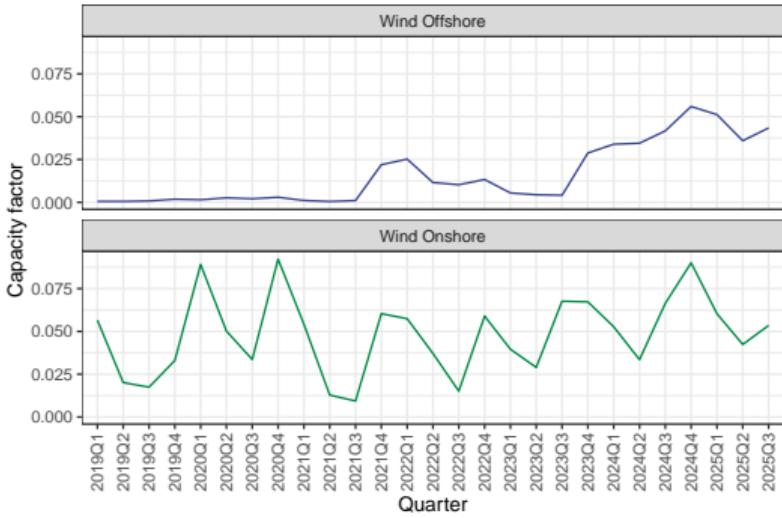


Curtailment through time

Curtailment by year

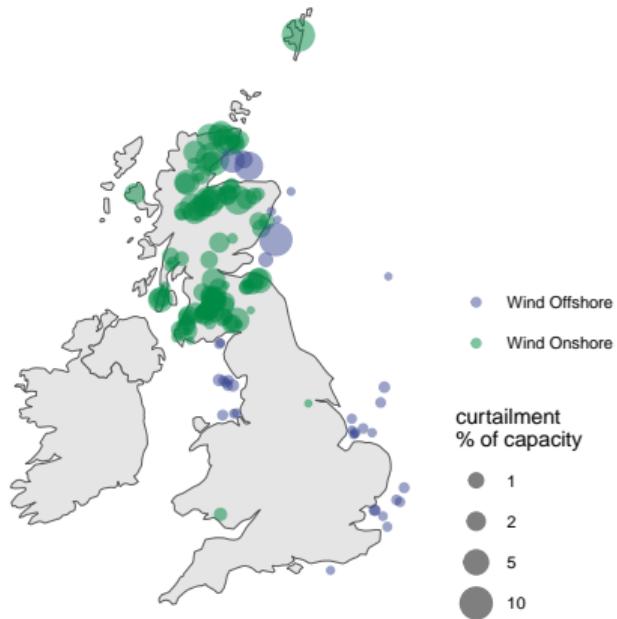


Curtailment seasonality

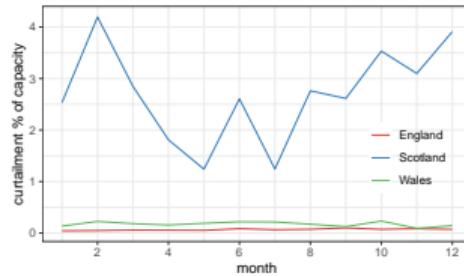


Curtailment

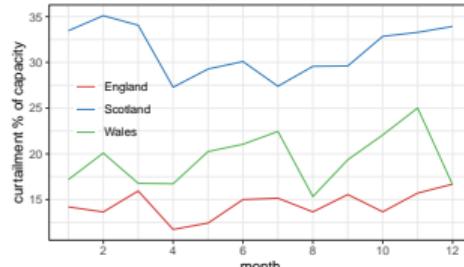
Curtailment map



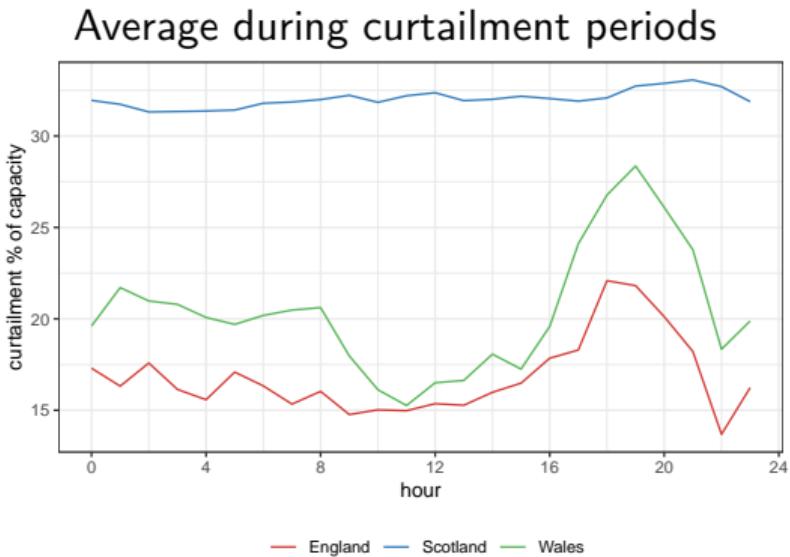
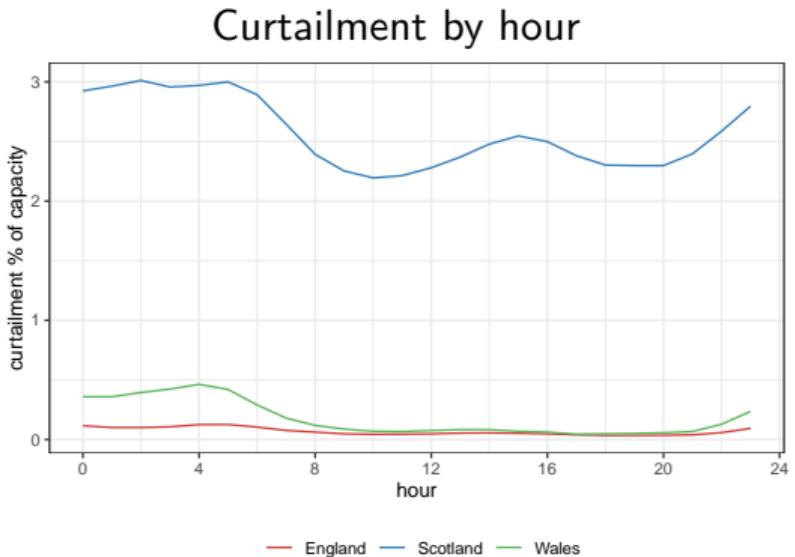
Curtailment by region



Average during curtailment periods

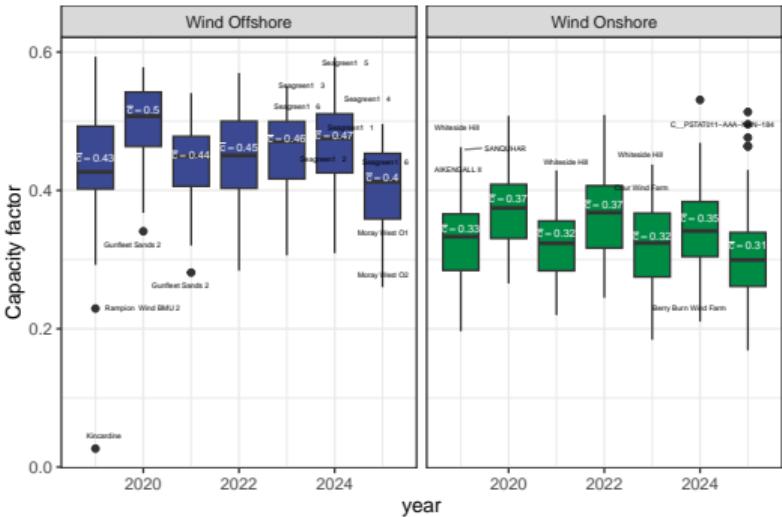


Curtailment through the day

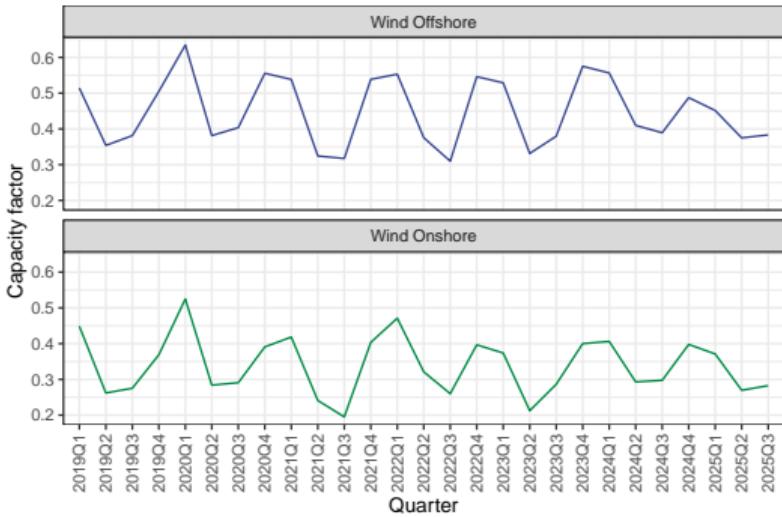


Potential generation

Potential by year



Potential seasonality



Renewable energy planning database (REPD)

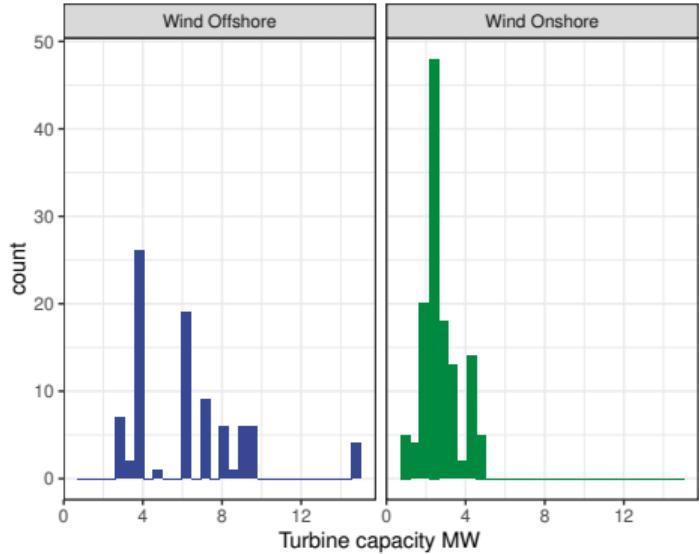
- Official UK government renewable data
- Over 800 wind farms listed as operational
- Coordinates available
- Also available:
 - Development status
 - Number of turbines
 - Turbine capacity
 - Turbine height (for some only)

REPD wind farms

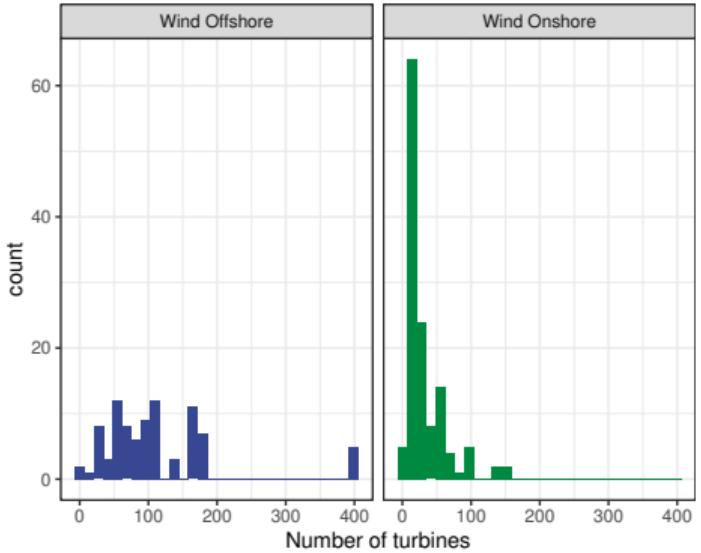
Type	Development Status	Count	Capacity MW
Wind Offshore	Operational	47	14,679
Wind Offshore	Under Construction	7	7,742
Wind Onshore	Operational	770	14,738
Wind Onshore	Under Construction	37	1,779
Total	-	861	38,938

Turbine data available

Turbine capacity histogram



Number of turbines histogram

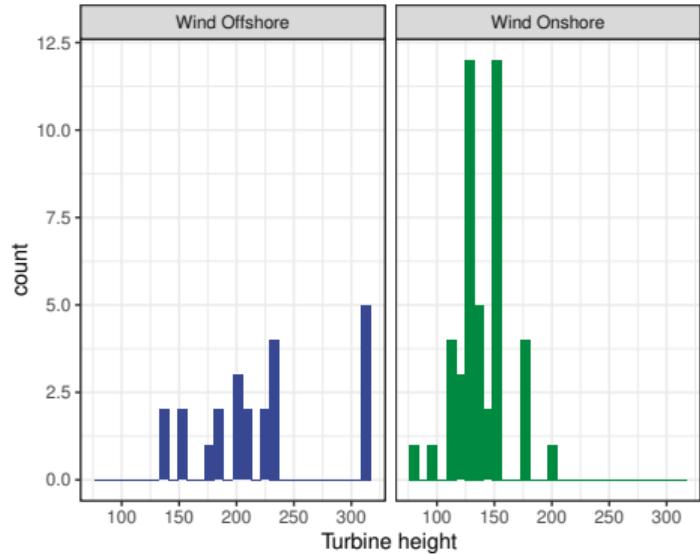


Turbine data available

Turbine Height availability

Type	Height available	Average height (m)	count
Wind Offshore	FALSE	222.0	23
Wind Offshore	TRUE	NaN	64
Wind Onshore	FALSE	137.7	45
Wind Onshore	TRUE	NaN	84

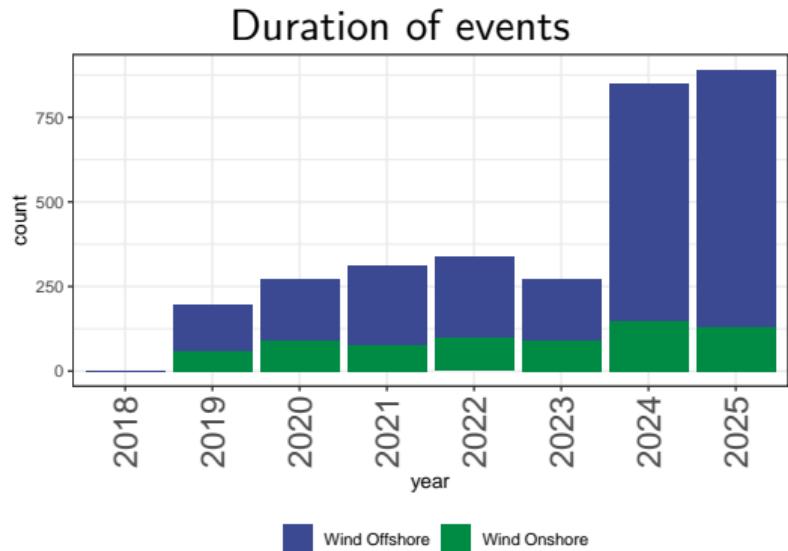
Turbine height histogram



Outages

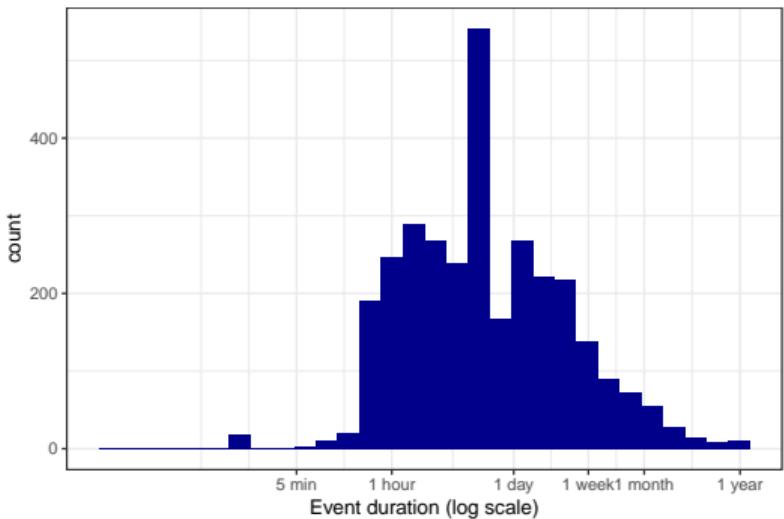
Outage data

- REMIT messages announce plan or unplanned outages
- event start / end times
- affected BMUs and capacity reduction

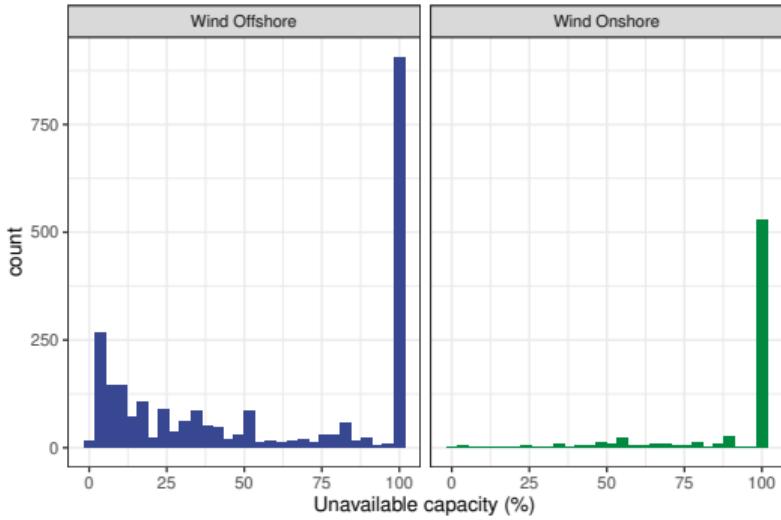


Outage characteristics

Number of events by year



Duration of events

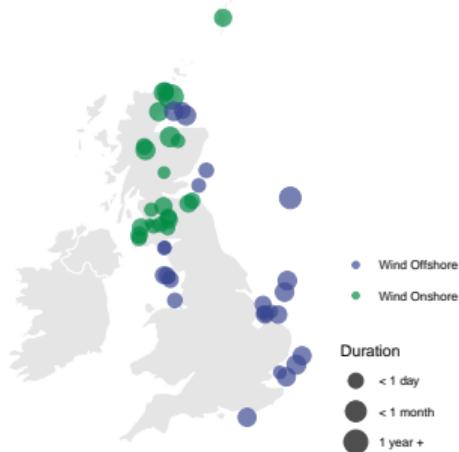


Outages characteristics by location

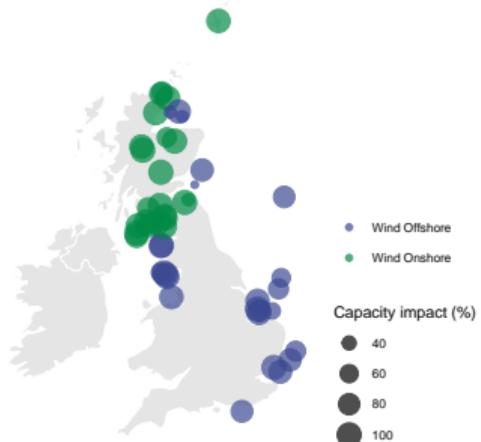
No. of events



Mean duration



Unavailable capacity



Power conversion

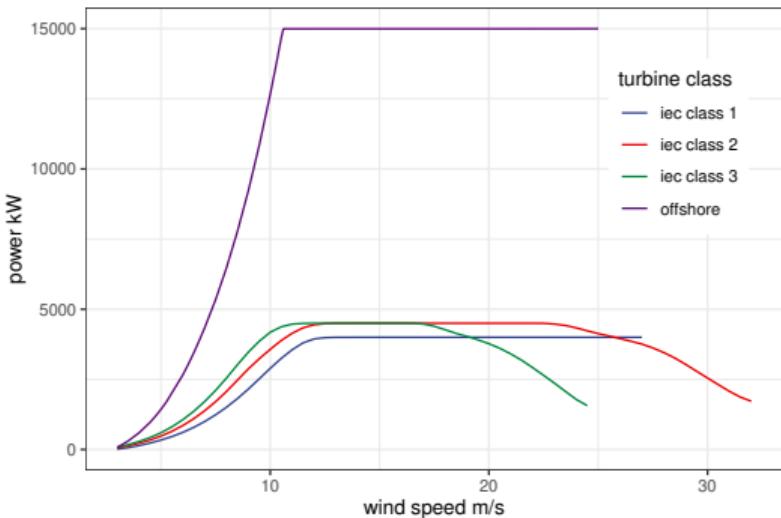
Generic power curves

- Using 3 generic power curves
- Offshore plus the IEC 3 classes
- Assigning class based on GWA mean wind speed at location
- Rescaling rated power to turbine capacity

IEC classification

Class	Mean wind speed at hub height (m/s)	Extreme 10-min gust (m/s)	Typical sites
I	10	70	Very windy / exposed sites
II	8.5	59.5	Moderate wind sites
III	7.5	52.5	Low-wind / inland sites

Generic power curves (PC_k)



Power estimate based on generic power curves

For each location i we have:

- observed raw power \tilde{p}_{it}
- curtailment amount a_{it}
- potential output $p_{it} = \tilde{p}_{it} + a_{it}$
- wind farm capacity c_i
- turbine height v_i
- ERA5 wind speed w_{it} .

Power estimate based on generic power curves

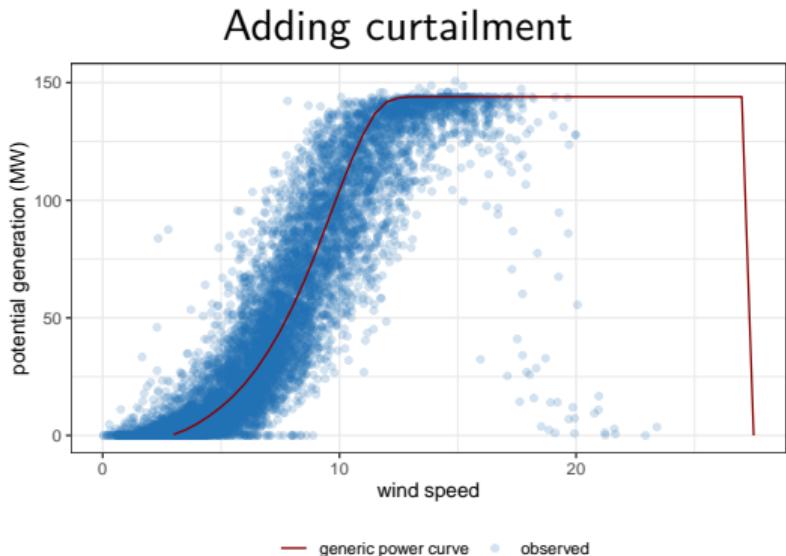
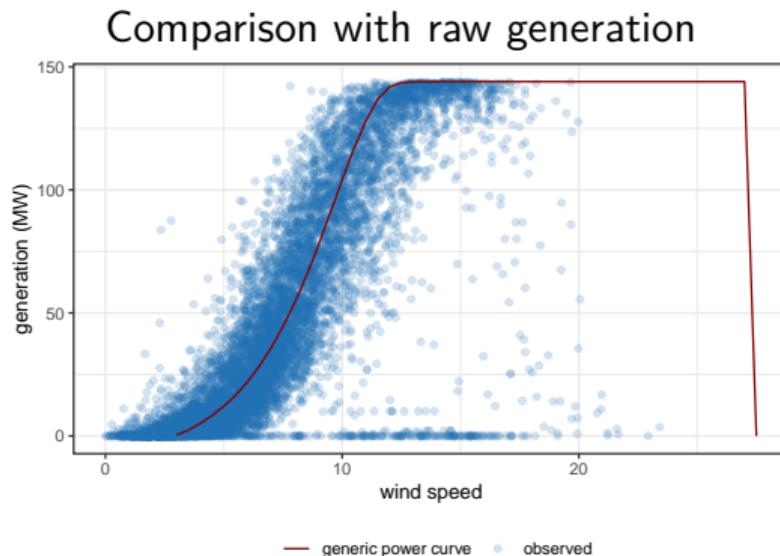
An initial estimate will require:

- Mapping location to a rescaled power curve \widetilde{PC}_k
- Estimate wind farm power in GWh

$$\hat{p}_{it} = \widetilde{PC}_k(w_{it})$$

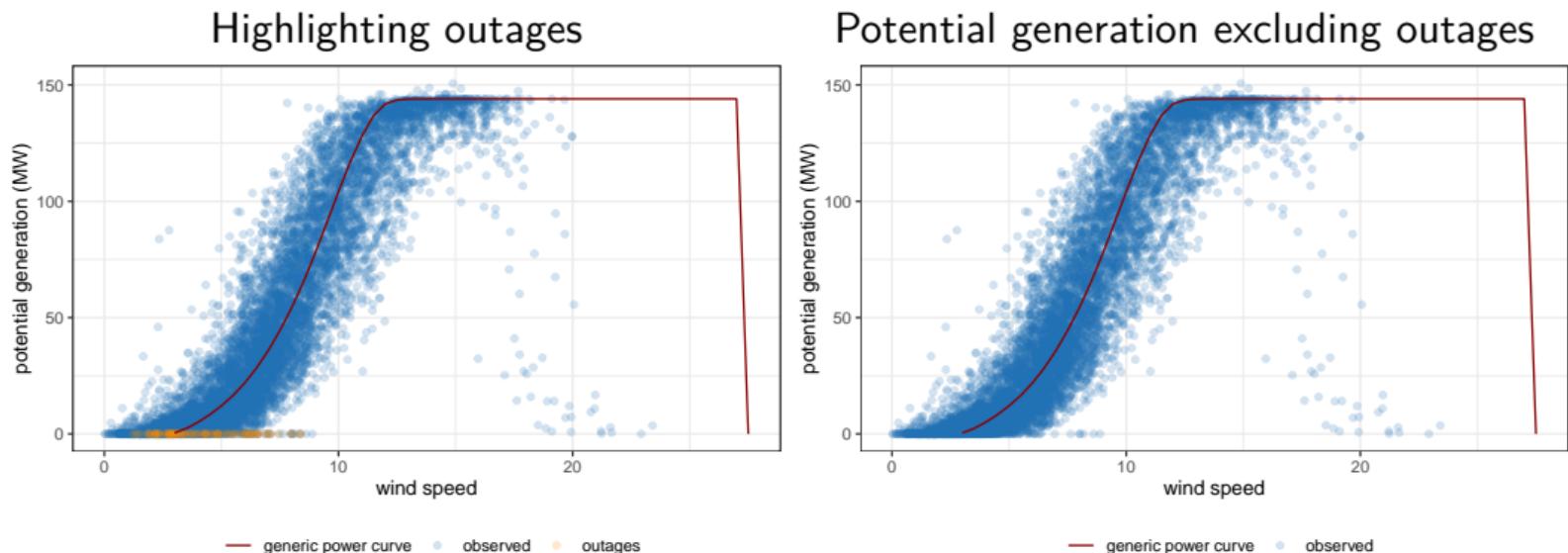
Generic power curves vs observed data - Fallago Rig

Onshore wind farm with moderate curtailment



Generic power curves vs observed data - Fallago Rig

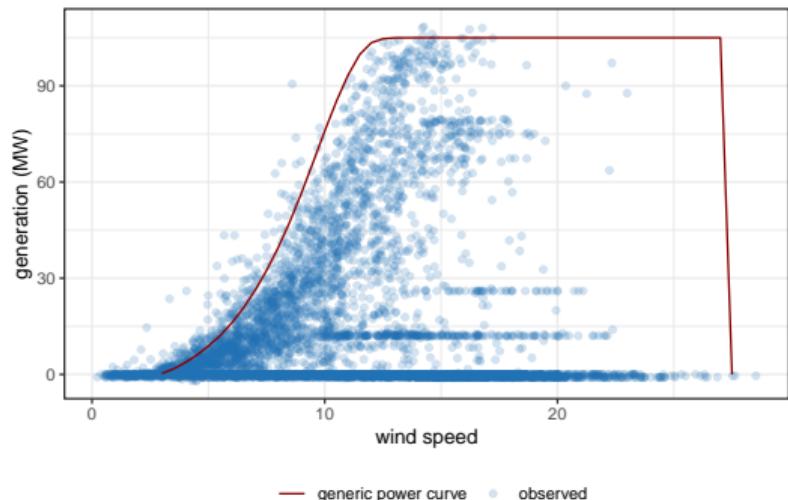
Onshore wind farm with moderate curtailment



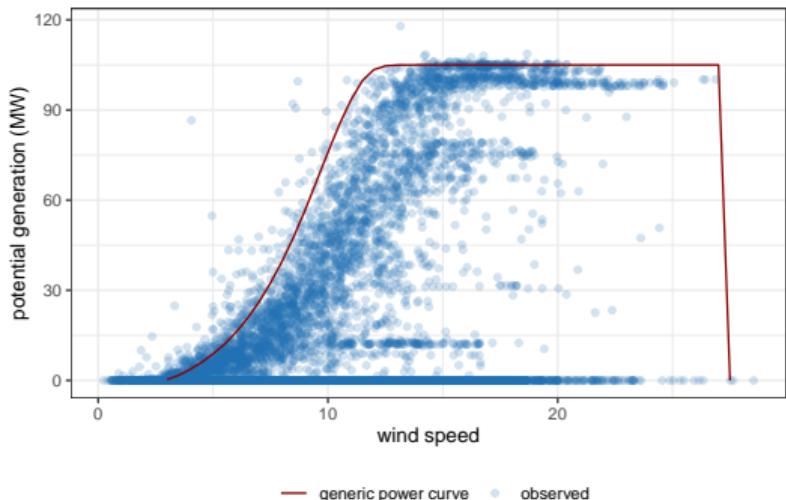
Generic power curves vs observed data - Viking

Onshore wind farm with high curtailment

Comparison with raw generation

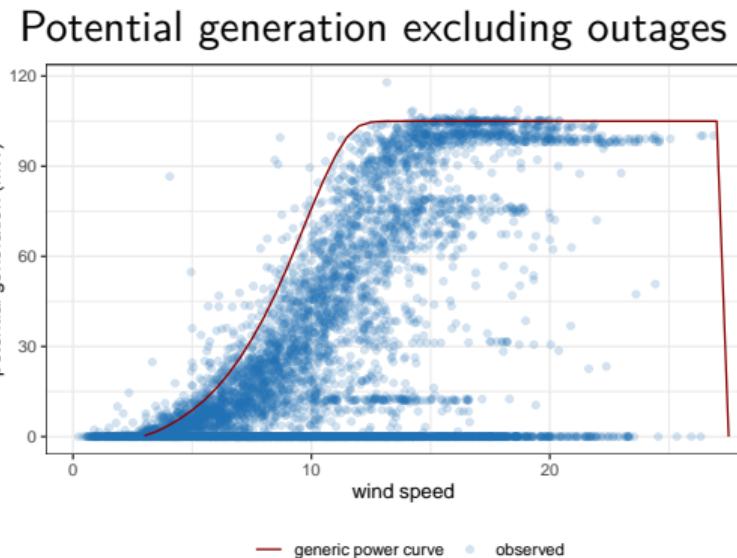
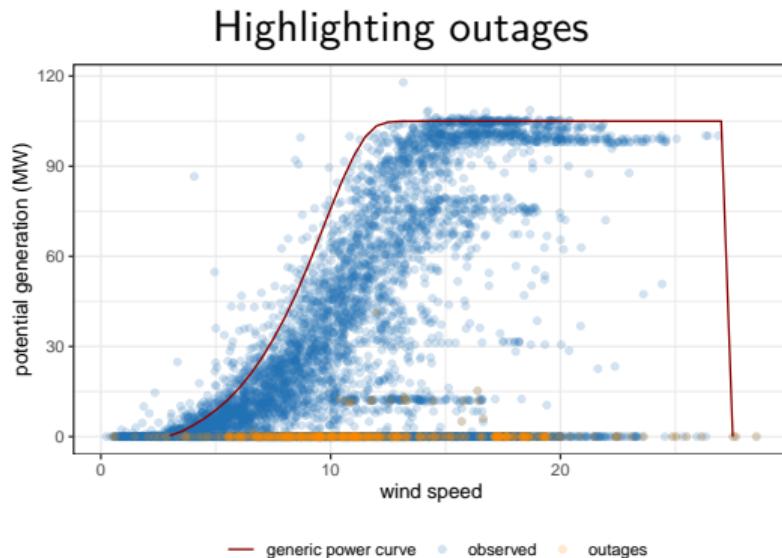


Adding curtailment



Generic power curves vs observed data - Viking

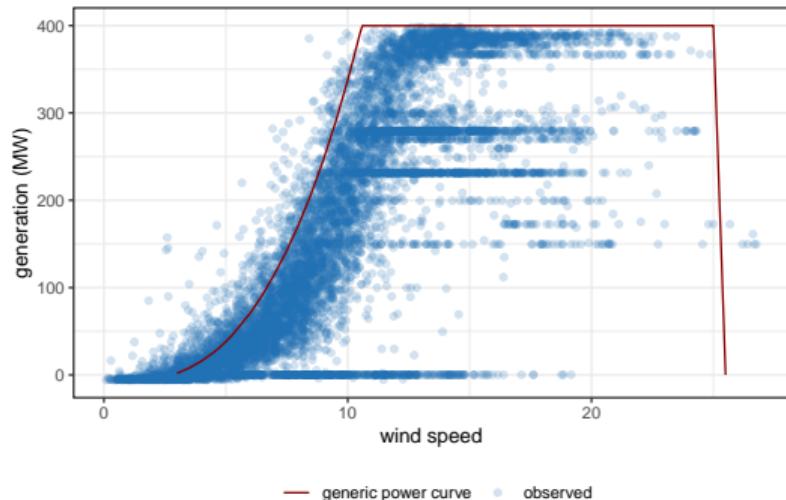
Onshore wind farm with high curtailment



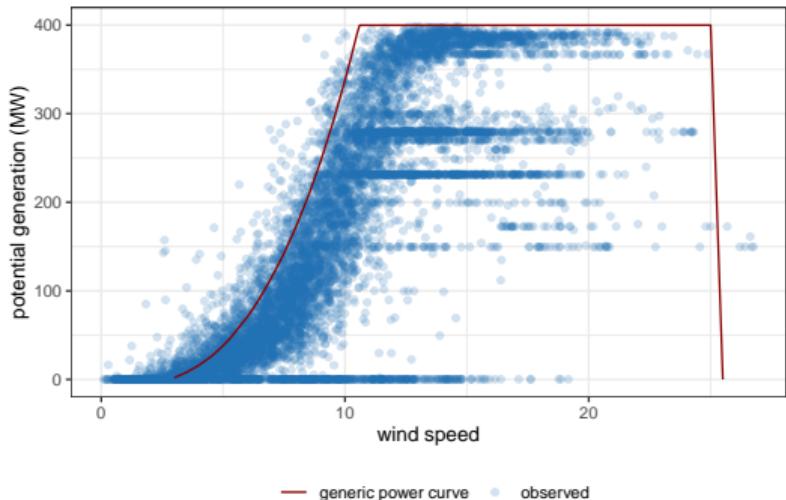
Generic power curves vs observed data - Hornsea 1

Offshore wind farm with low curtailment

Comparison with raw generation

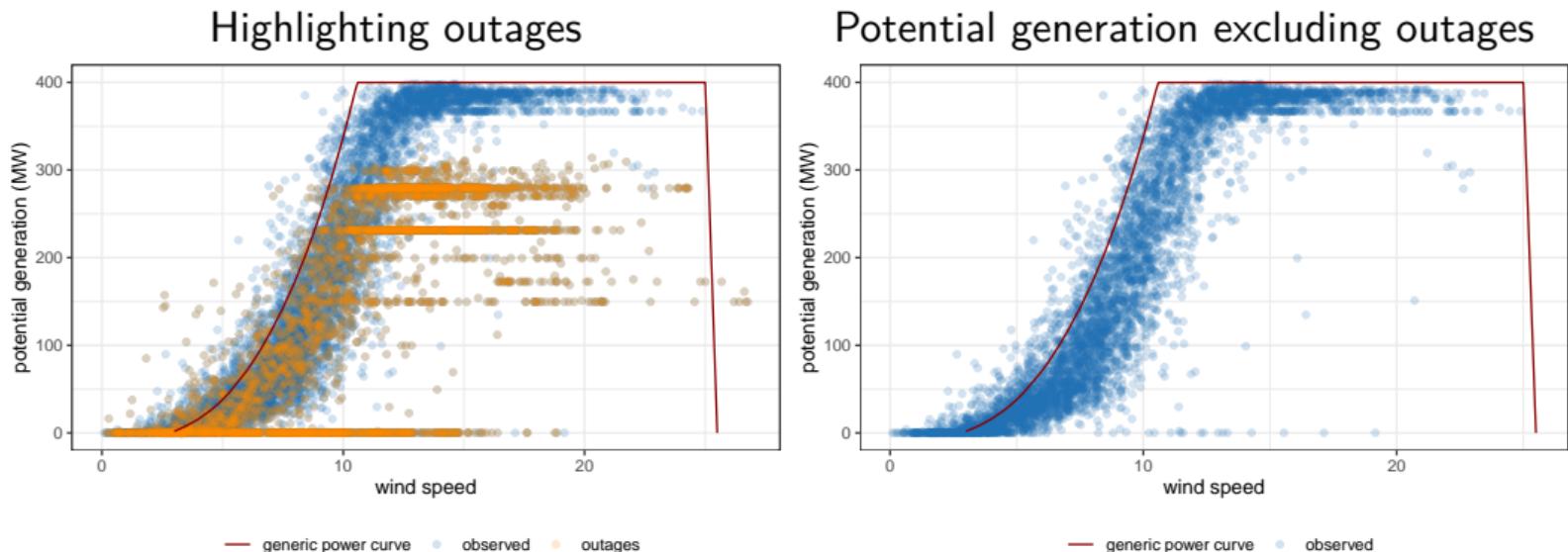


Adding curtailment



Generic power curves vs observed data - Hornsea 1

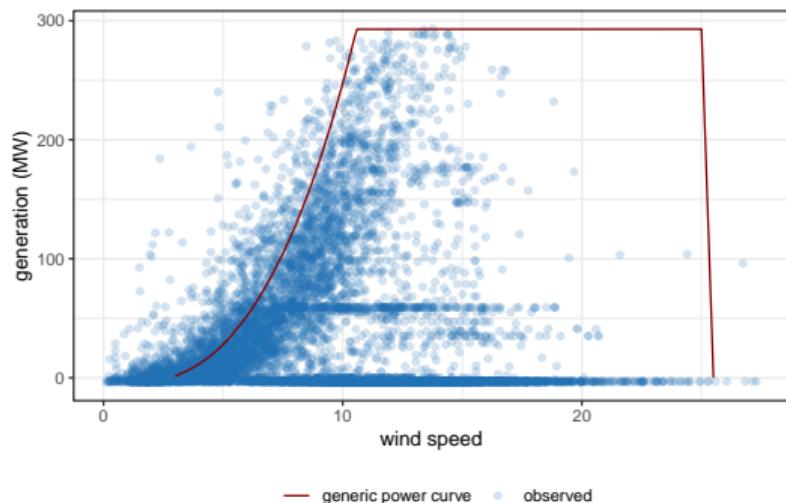
Offshore wind farm with low curtailment



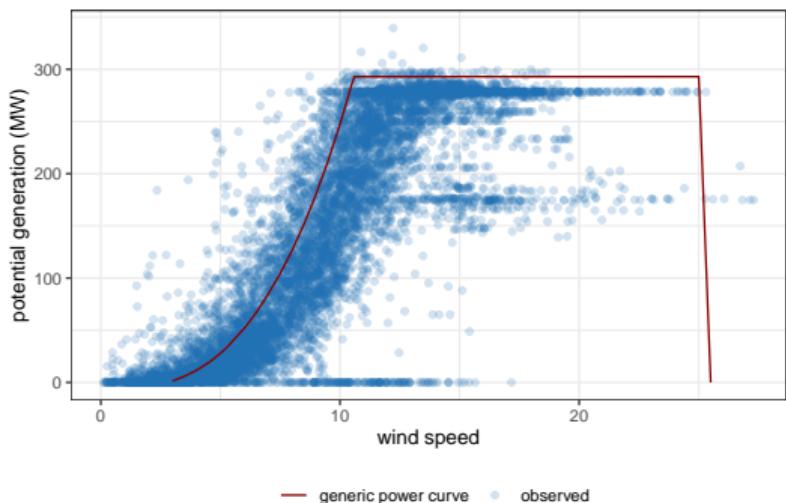
Generic power curves vs observed data - Seagreen 1

Offshore wind farm with high curtailment

Comparison with raw generation

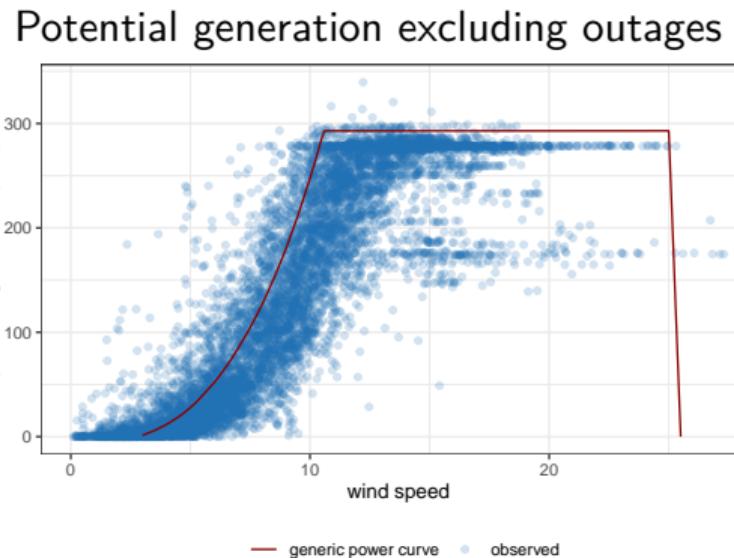
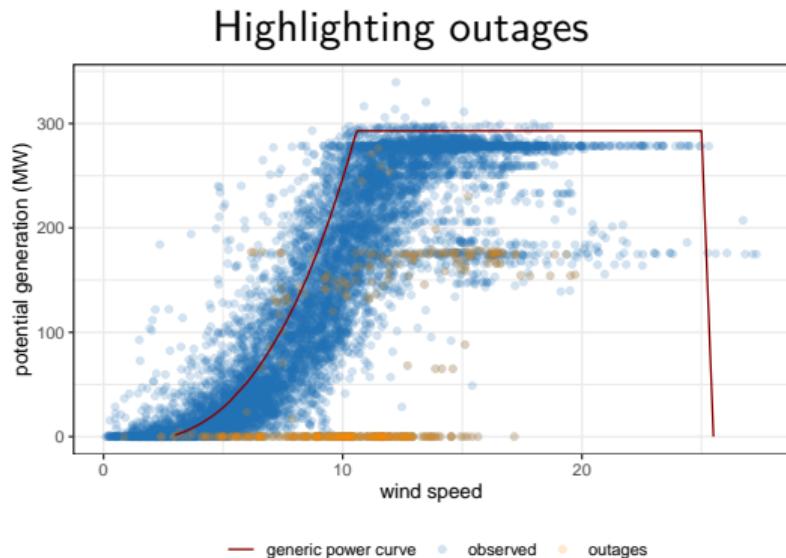


Adding curtailment



Generic power curves vs observed data - Seagreen 1

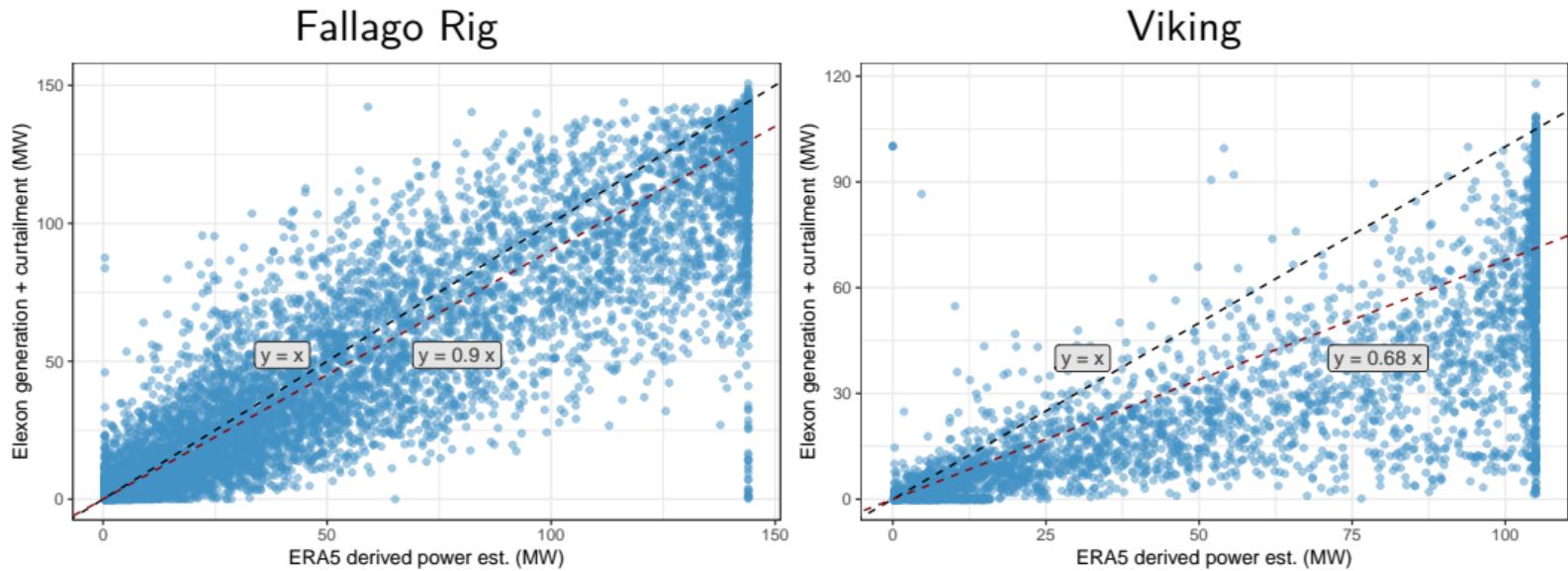
Offshore wind farm with high curtailment



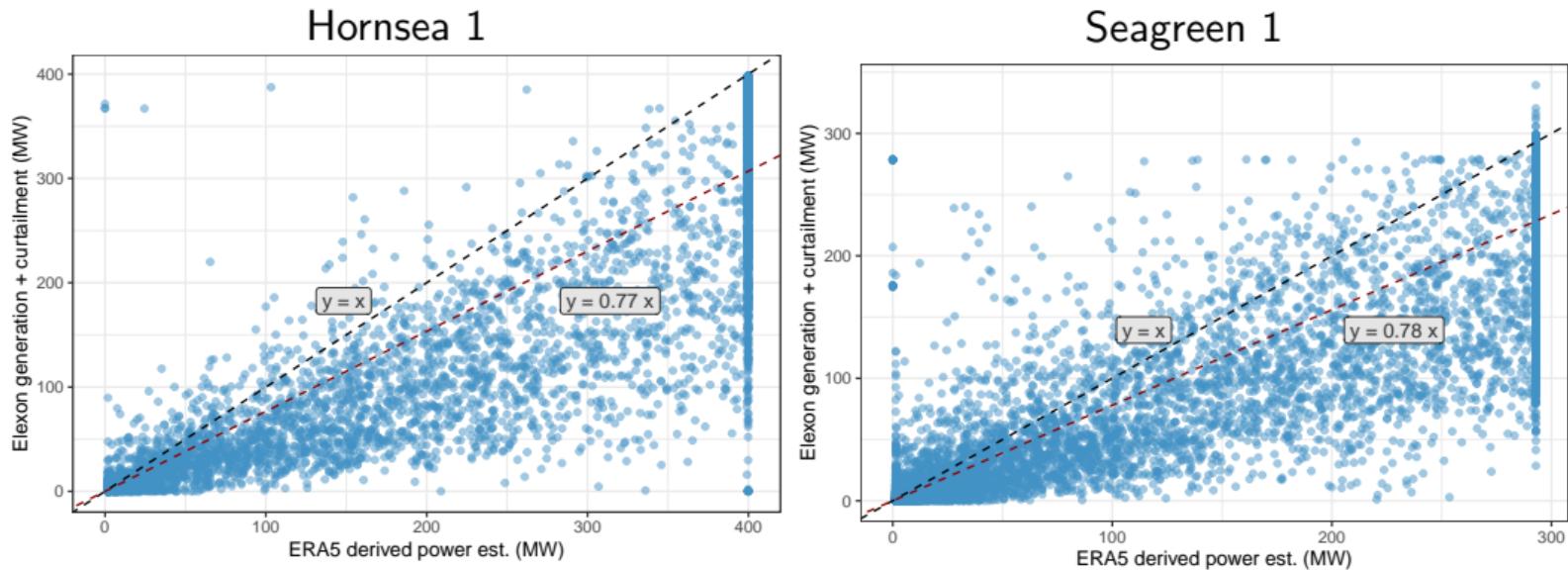
ERA5 based estimates vs Elexon 2024

- Remove periods with outages
- Vertical interpolation of ERA5 wind speed to turbine height
- Apply generic power curve to get estimated power

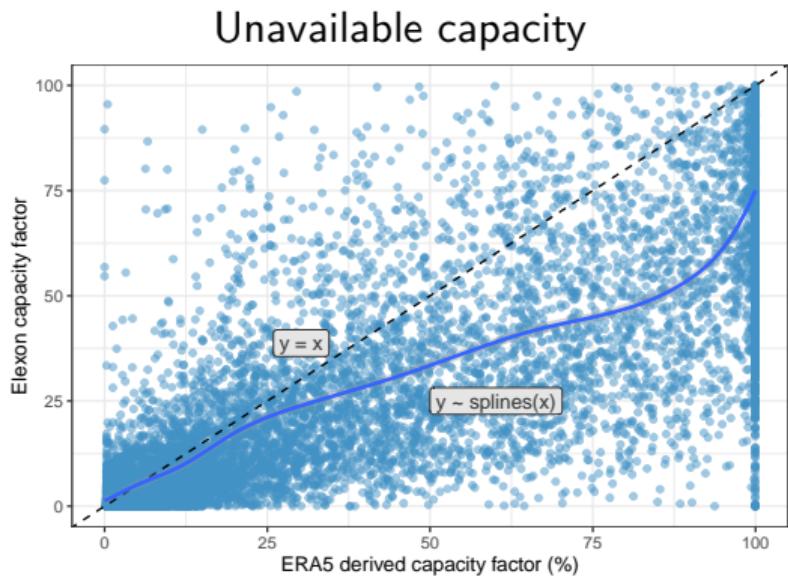
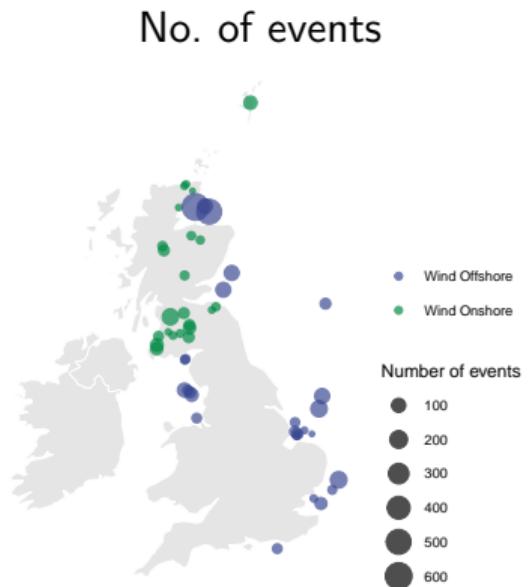
ERA5 based estimates vs Elexon 2024



ERA5 based estimates vs Elexon 2024



Comparison for all wind farms



Next Steps

- Learn power curve from history
- Model for calibration
- Quantile mapping calibration