

# ERA 5 calibration to Elexon power

S. Gomez<sup>1</sup>

<sup>1</sup>School of Mathematics, University of Edinburgh

2025-11-04

# Table of contents I

1 Calibration to power

2 ERA5

3 Elexon data

4 Outages

5 Power conversion

Calibration to power

# Updates

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

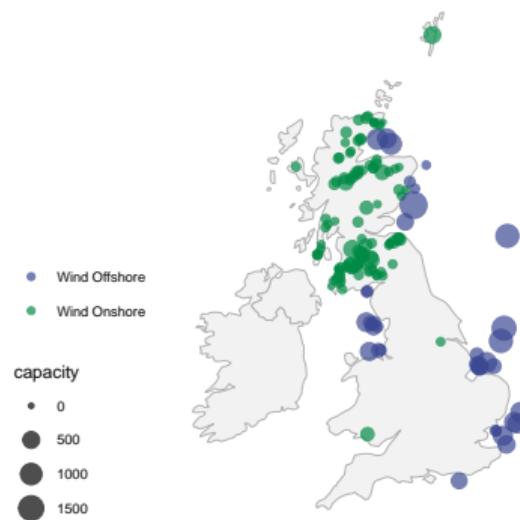
# ERA5 vs Elexon generation

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

**ERA5 at wind farms**



**Elexon wind farms map (2025)**

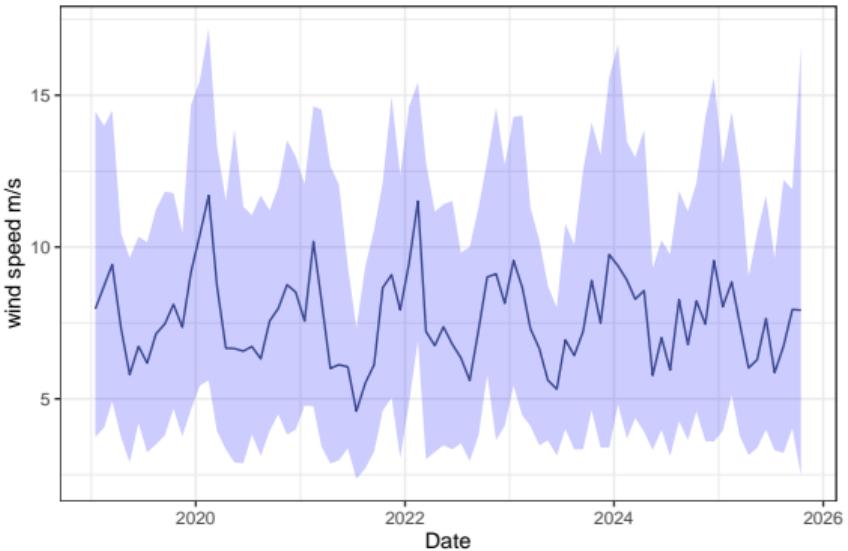


ERA5

# Characteristics

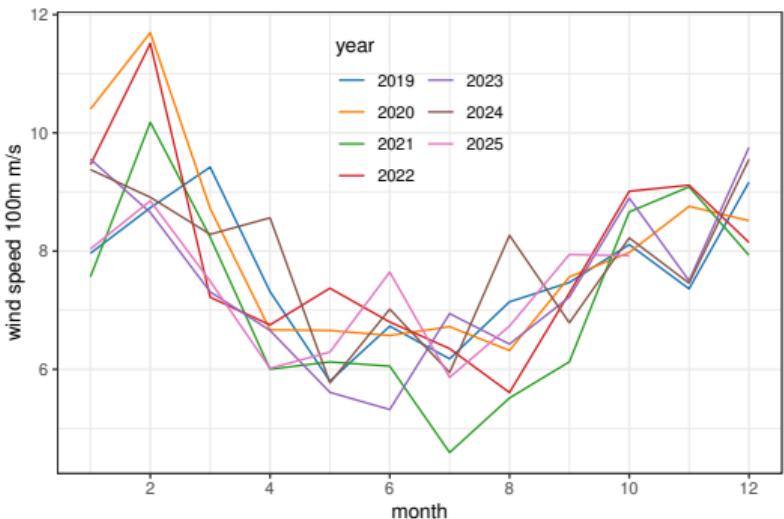
- 5th generation of ECMWF's global reanalysis
- Spatial resolution  $0.25^\circ \times 0.25^\circ$  (31km  $\times$  31 km at equator)
- Hourly temporal resolution
- Heights: 10m, 100m

Average monthly wind speed and 90 CI

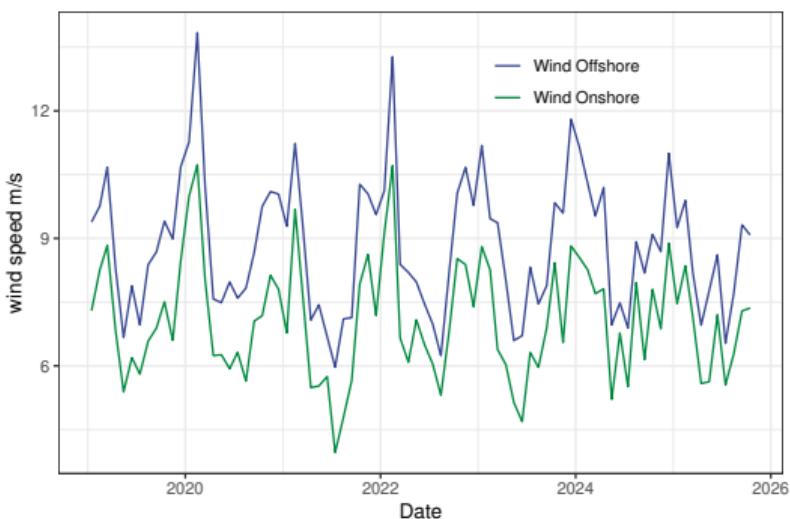


# ERA5 series

Wind speed seasonality



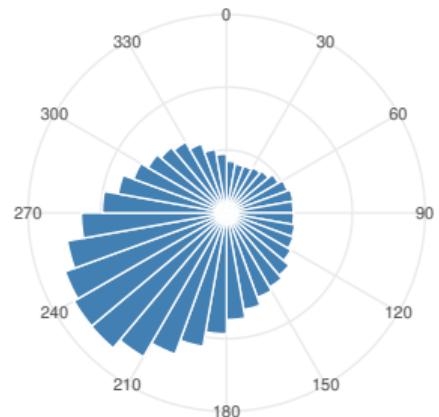
Wind speed by location type



# ERA5 wind direction at wind farms

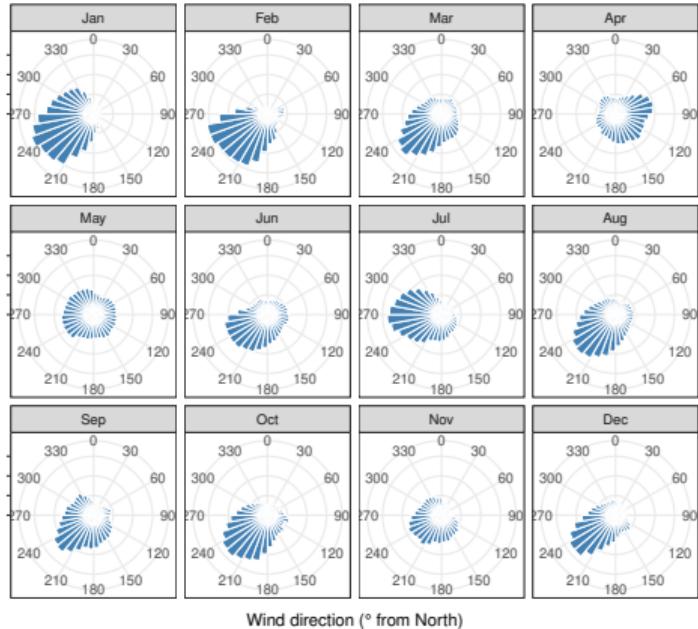
## Wind direction frequency

Radial Histogram of Wind Direction (100 m)



## Seasonal patterns

Radial Histogram of Wind Direction (100 m)

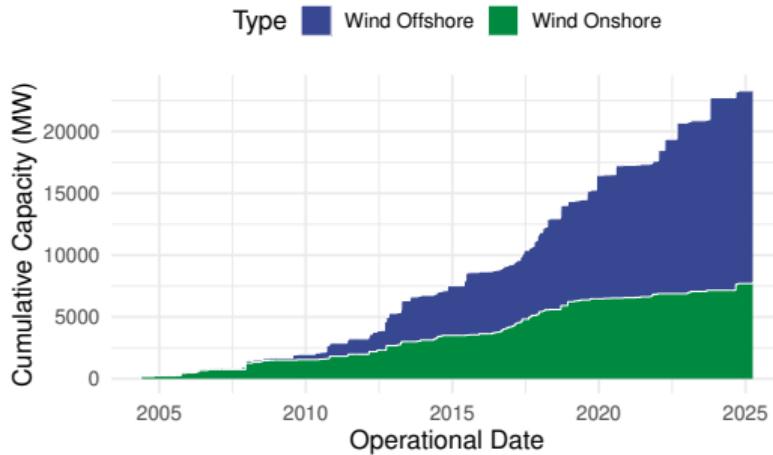


Elexon data

# 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

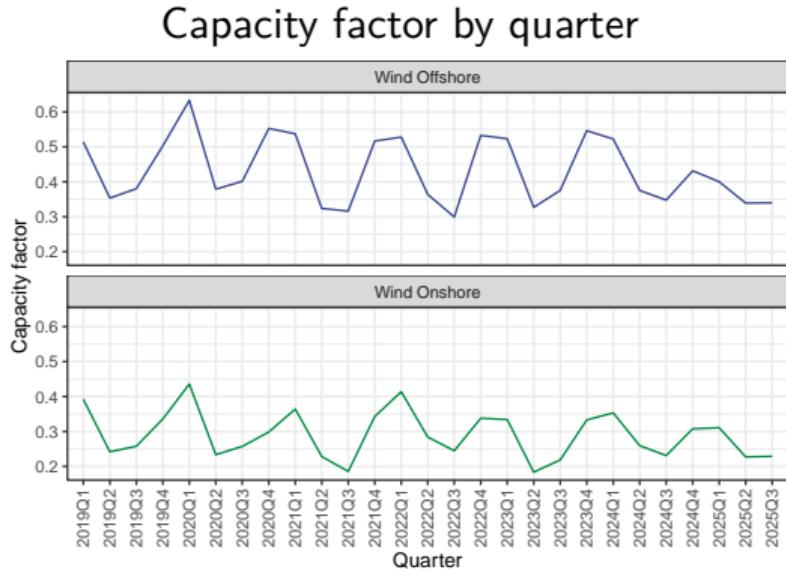
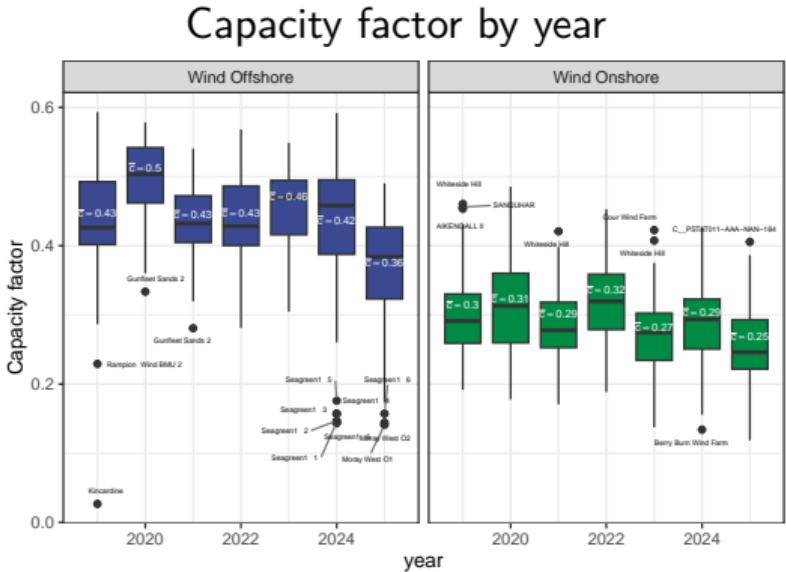


# BMU wind data

BMU wind generation (2024)

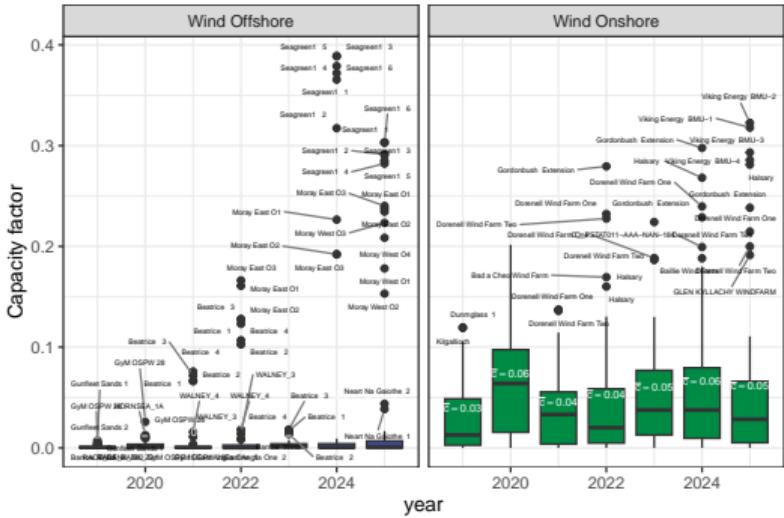
Type	Generation (GWh)	Curtailment	Potential	Capacity (MW)	Number of BMUs	CF	PF
Wind Offshore	46,907	4,902	51,810	15,563	80	0.42	0.47
Wind Onshore	16,254	3,363	19,617	7,860	123	0.29	0.34
Total	63,162	8,266	71,427	23,423	203	0.37	0.42

# Capacity factor through time

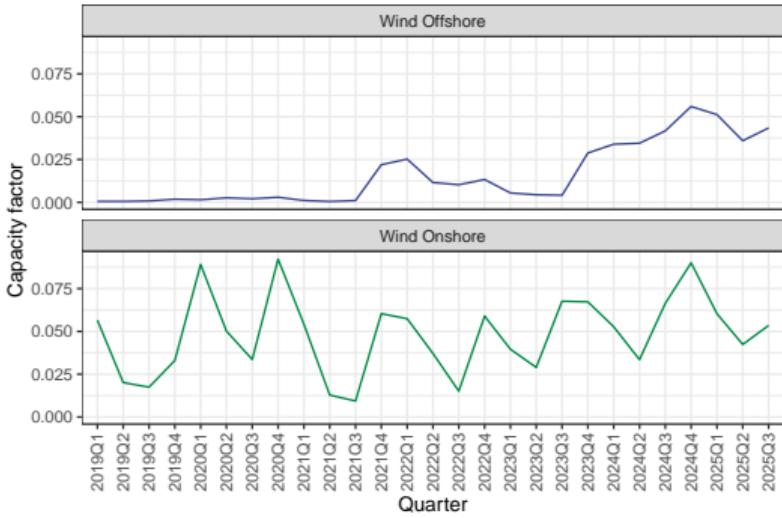


# Curtailment through time

## Curtailment by year

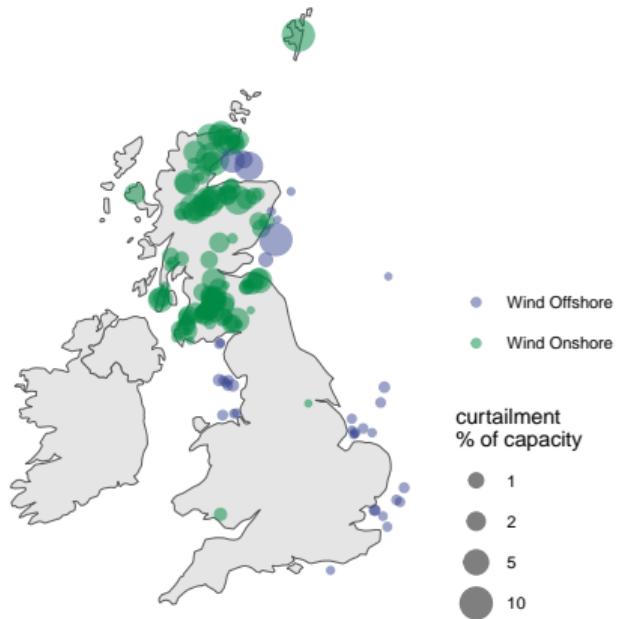


## Curtailment seasonality

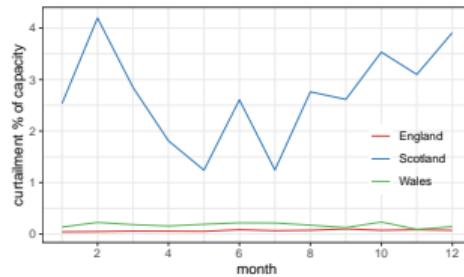


# Curtailment

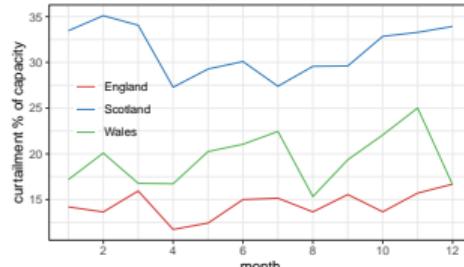
Curtailment map



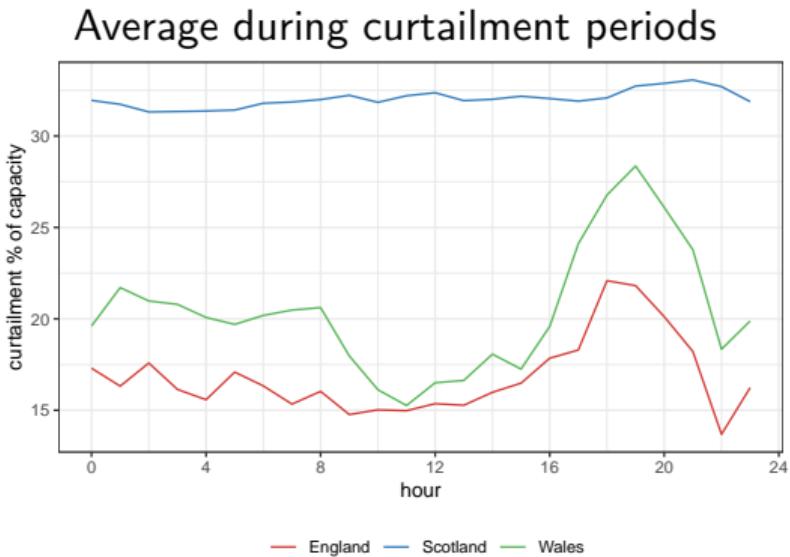
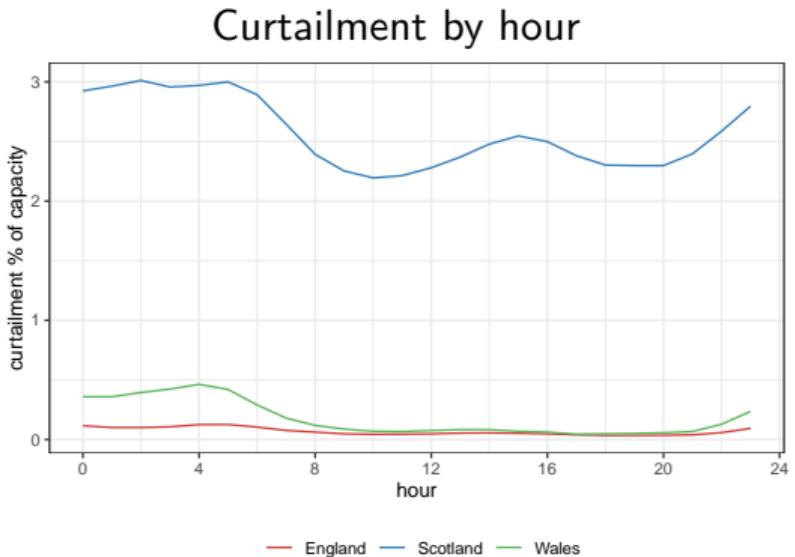
Curtailment by region



Average during curtailment periods

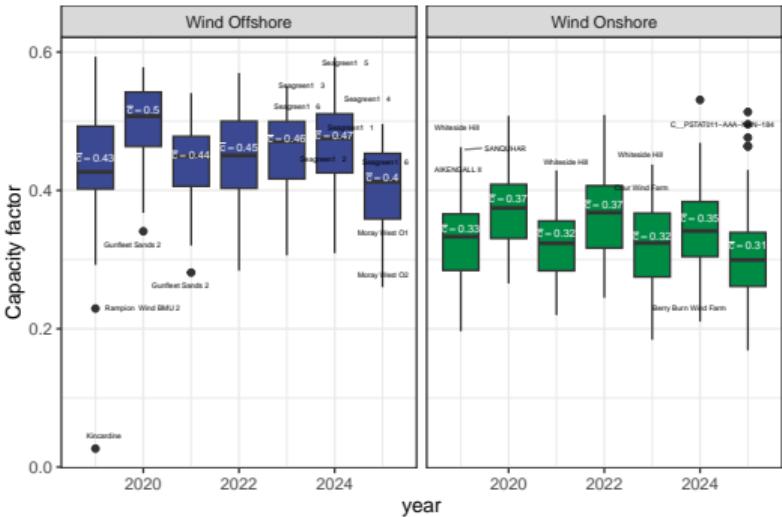


# Curtailment through the day

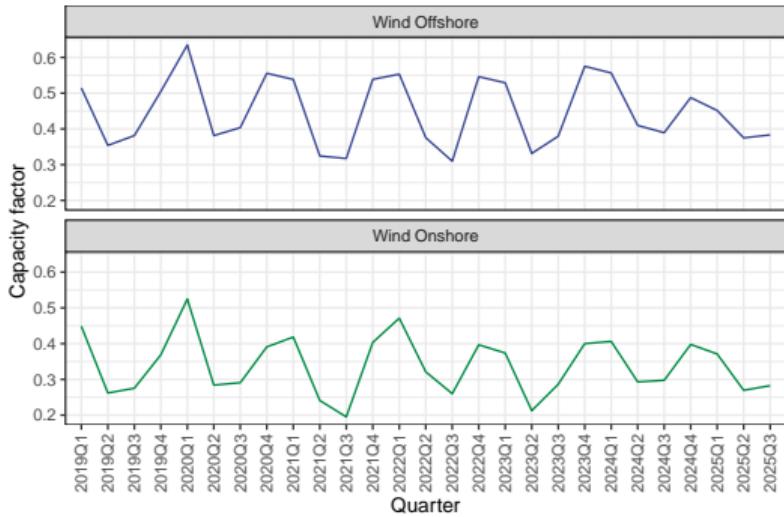


# Potential generation

## Potential by year



## Potential seasonality



# Renewable energy planning database (REPD)

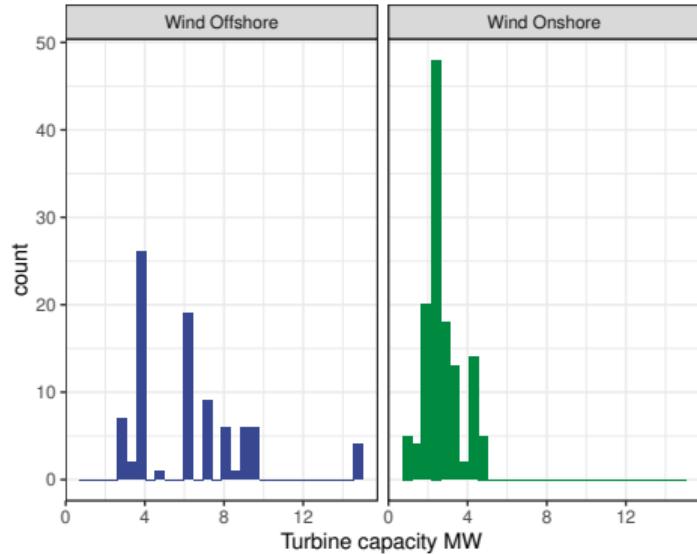
- Official UK government renewable data
- Over 800 wind farms listed as operational
- Coordinates available
- Also available:
  - Development status
  - Number of turbines
  - Turbine capacity
  - Turbine height (for some only)

REPD wind farms

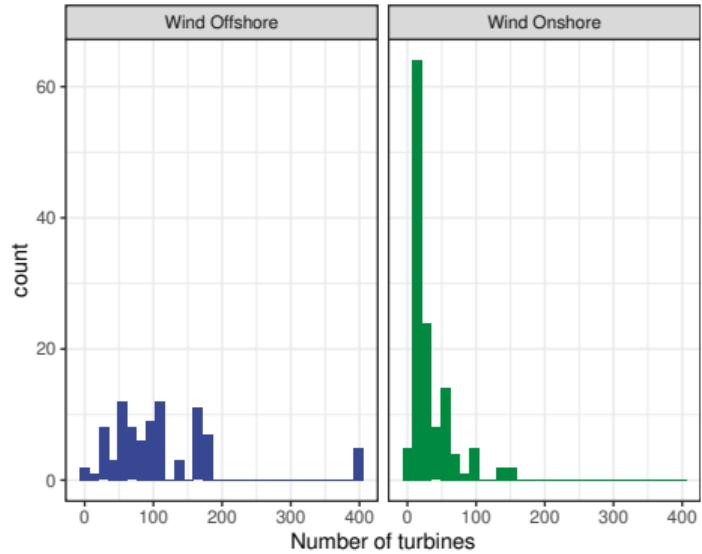
Type	Development Status	Count	Capacity MW
Wind Offshore	Operational	47	14,679
Wind Offshore	Under Construction	7	7,742
Wind Onshore	Operational	770	14,738
Wind Onshore	Under Construction	37	1,779
Total	-	861	38,938

# Turbine data available

Turbine capacity histogram



Number of turbines histogram

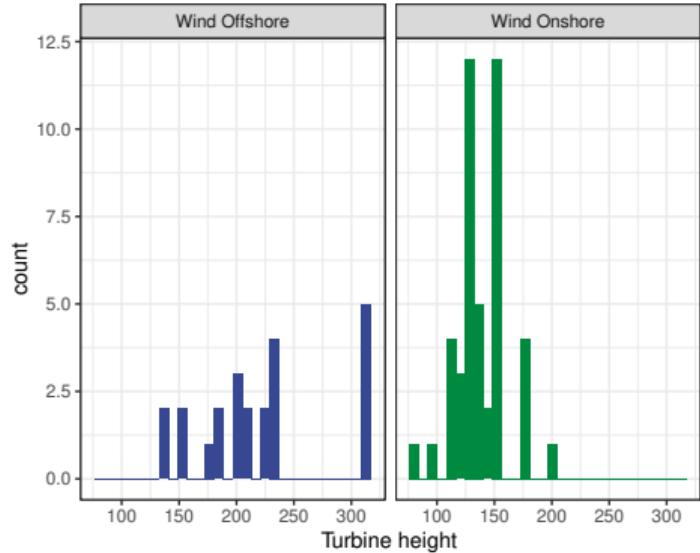


# Turbine data available

## 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

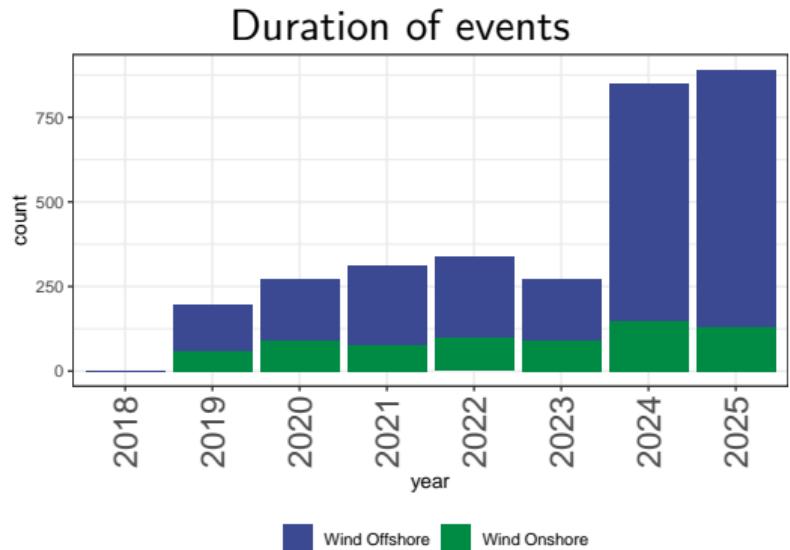
## Turbine height histogram



# Outages

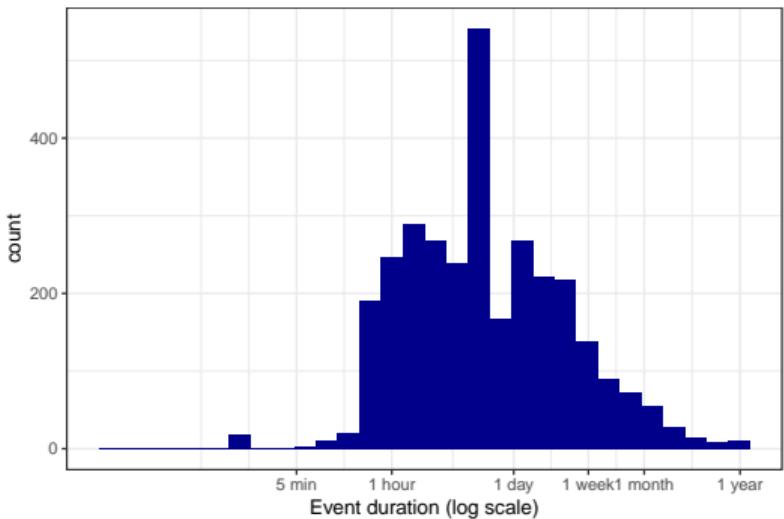
# Outage data

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

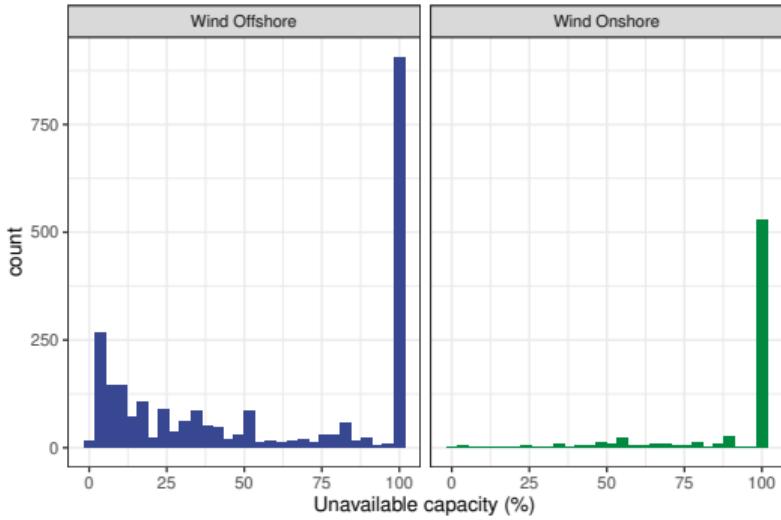


# Outage characteristics

Number of events by year

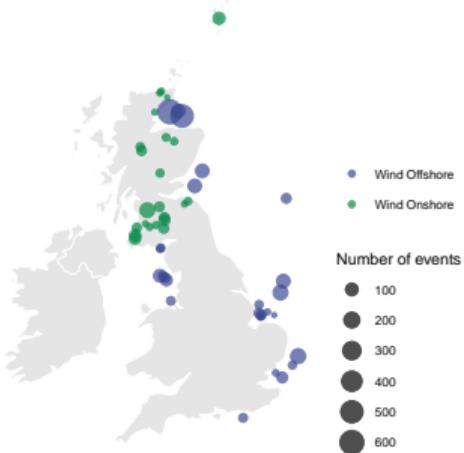


Duration of events

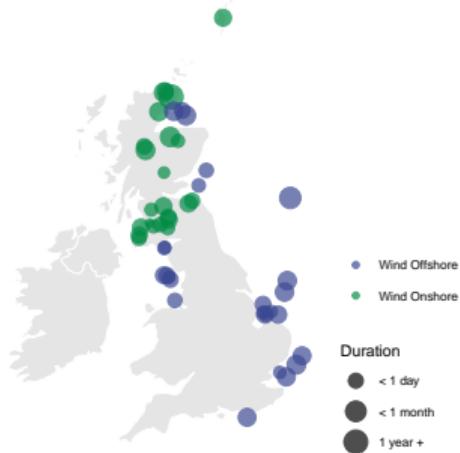


# Outages characteristics by location

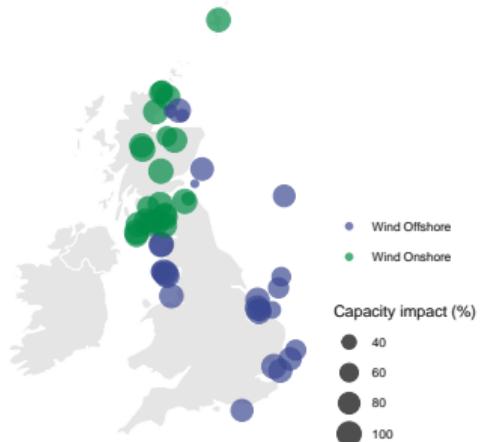
No. of events



Mean duration



Unavailable capacity



Power conversion

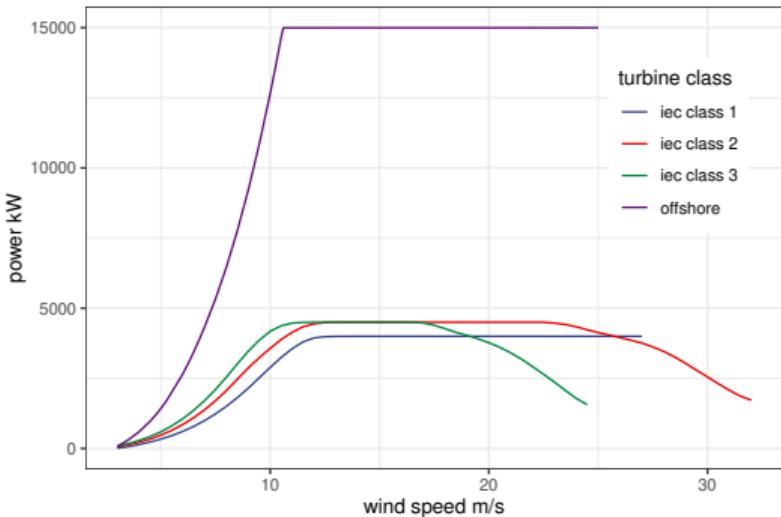
# Generic power curves

- 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

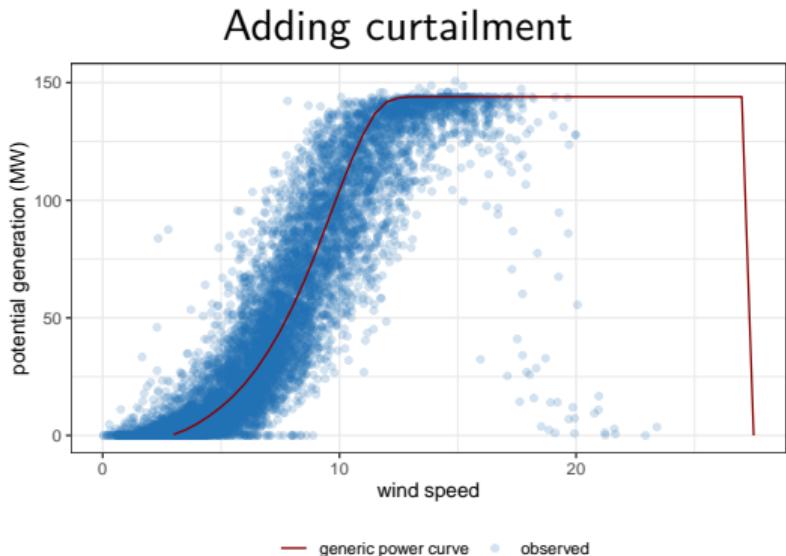
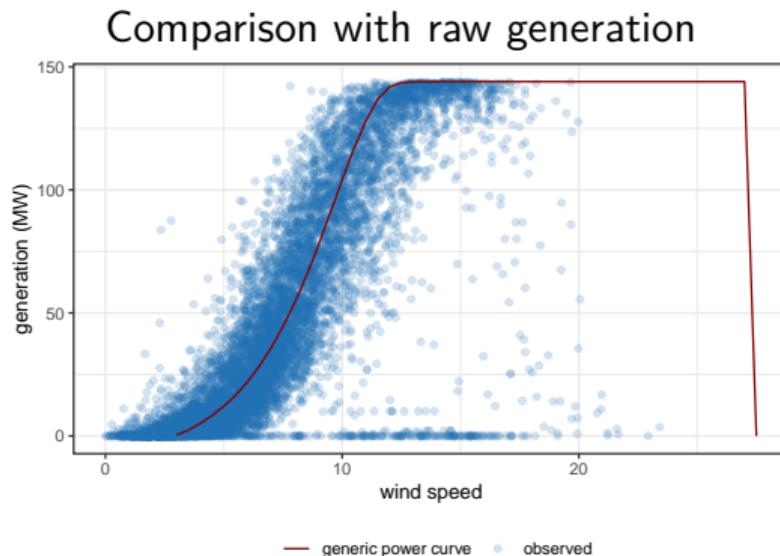
An initial estimate will require:

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

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

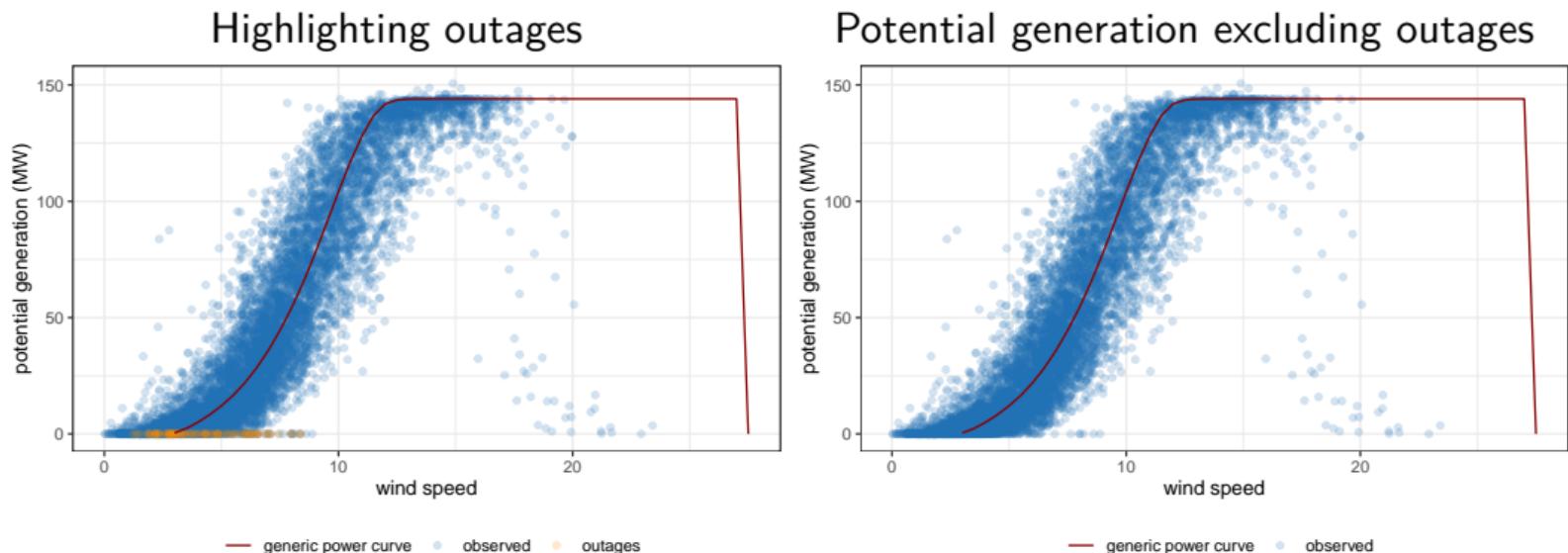
# Generic power curves vs observed data - Fallago Rig

Onshore wind farm with moderate curtailment



# Generic power curves vs observed data - Fallago Rig

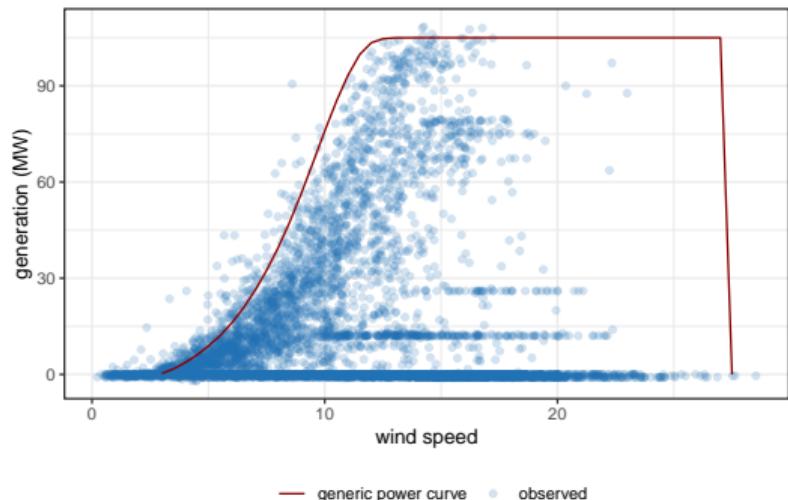
Onshore wind farm with moderate curtailment



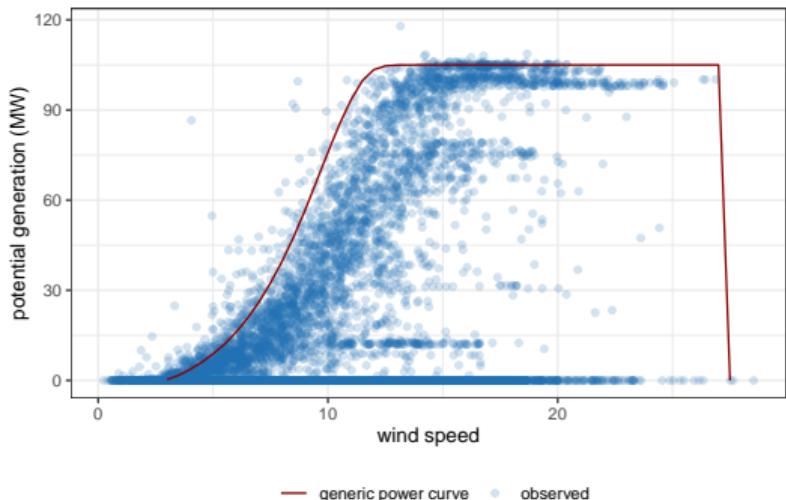
# Generic power curves vs observed data - Viking

Onshore wind farm with high curtailment

Comparison with raw generation

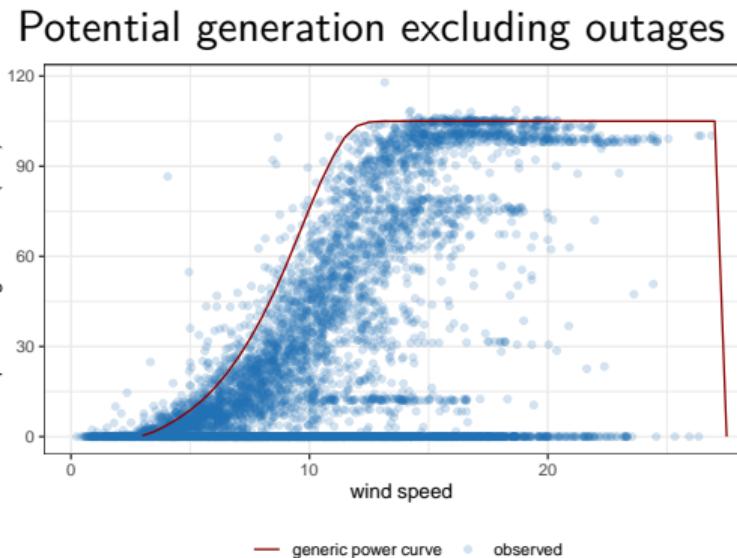
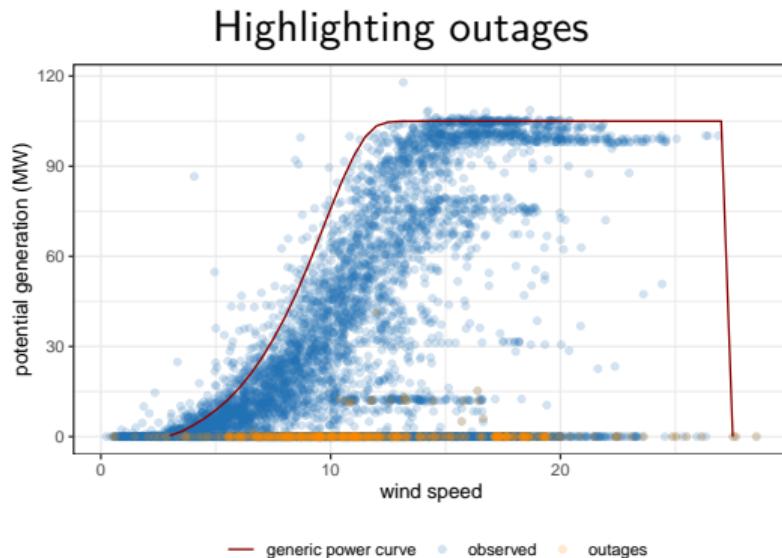


Adding curtailment



# Generic power curves vs observed data - Viking

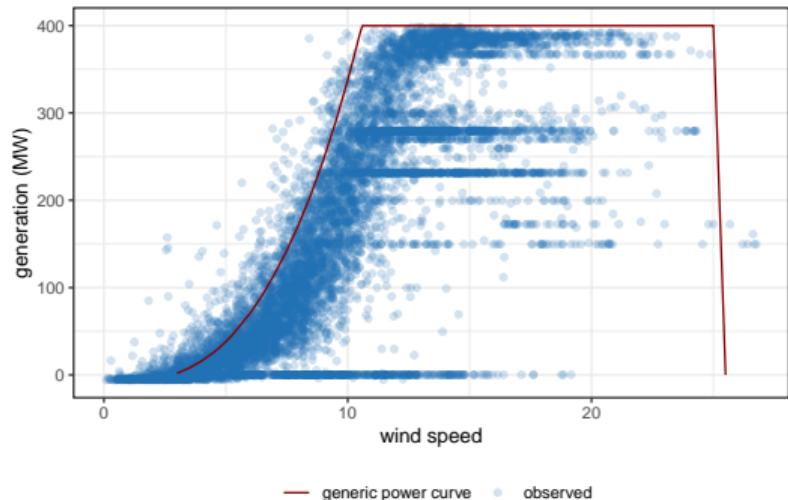
Onshore wind farm with high curtailment



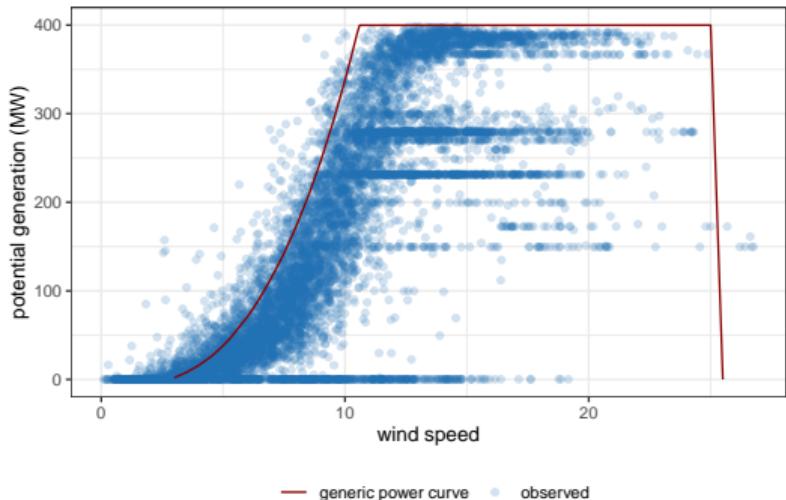
# Generic power curves vs observed data - Hornsea 1

Offshore wind farm with low curtailment

Comparison with raw generation

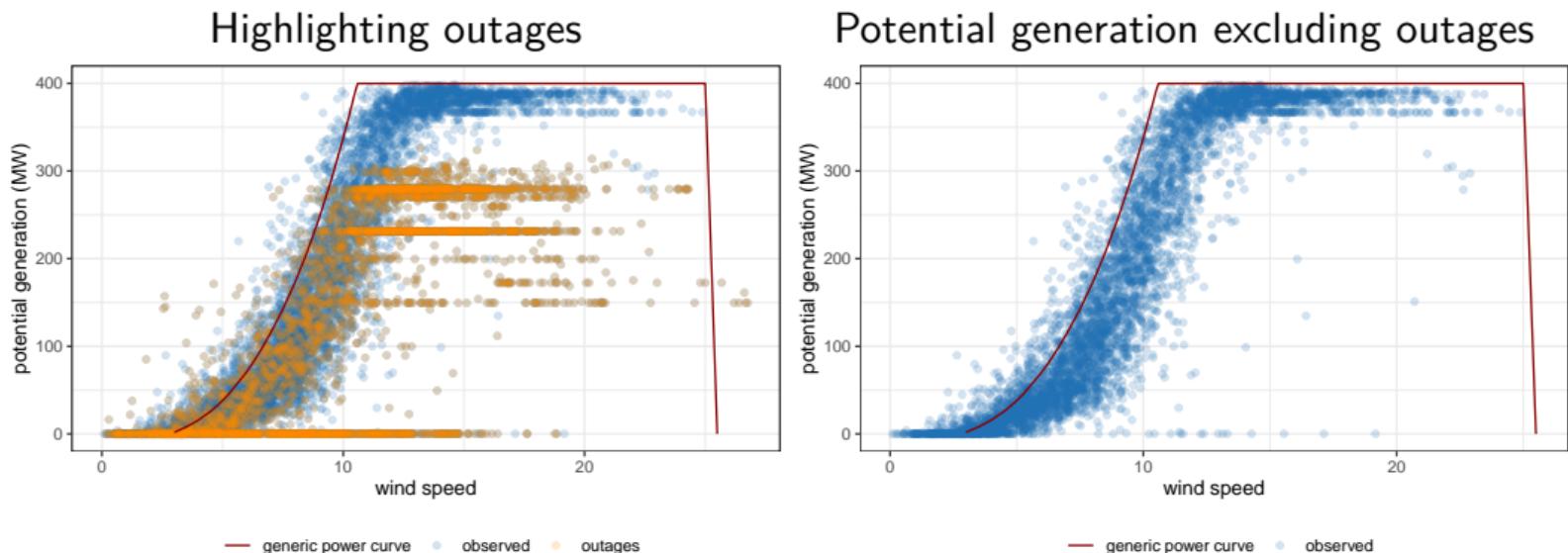


Adding curtailment



# Generic power curves vs observed data - Hornsea 1

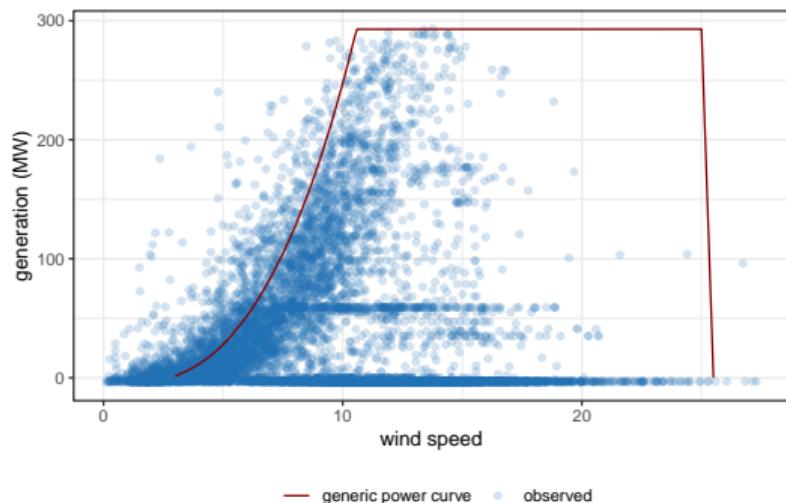
Offshore wind farm with low curtailment



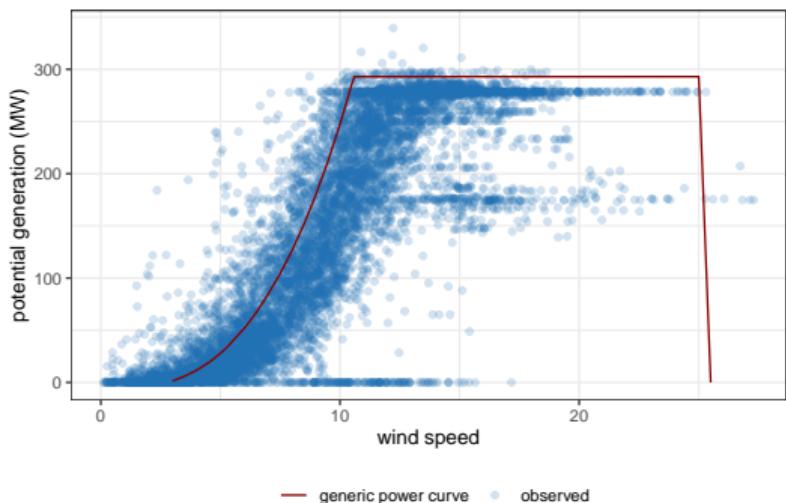
# Generic power curves vs observed data - Seagreen 1

Offshore wind farm with high curtailment

Comparison with raw generation

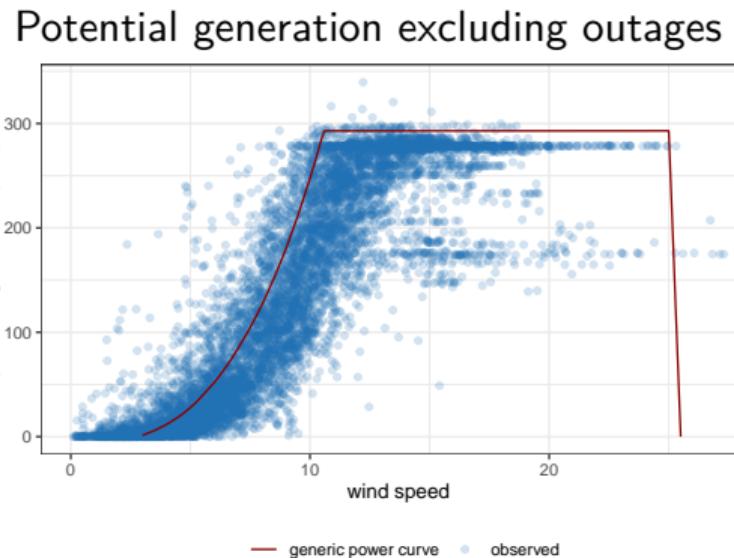
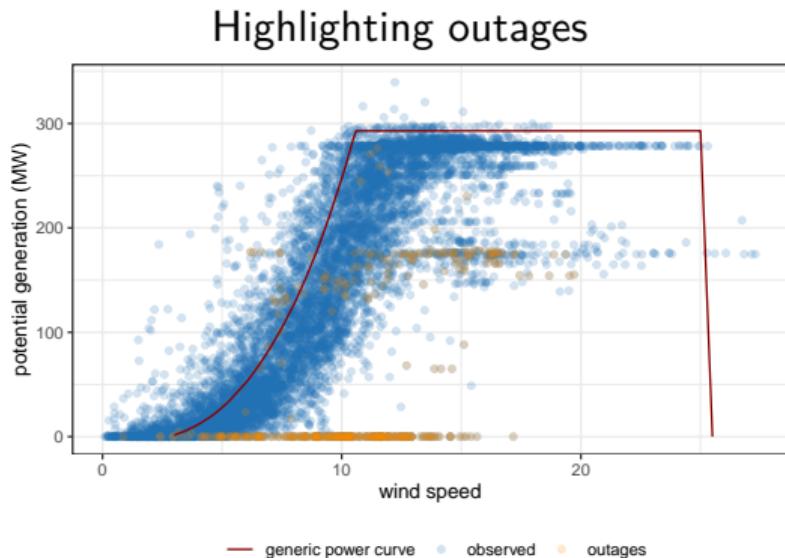


Adding curtailment

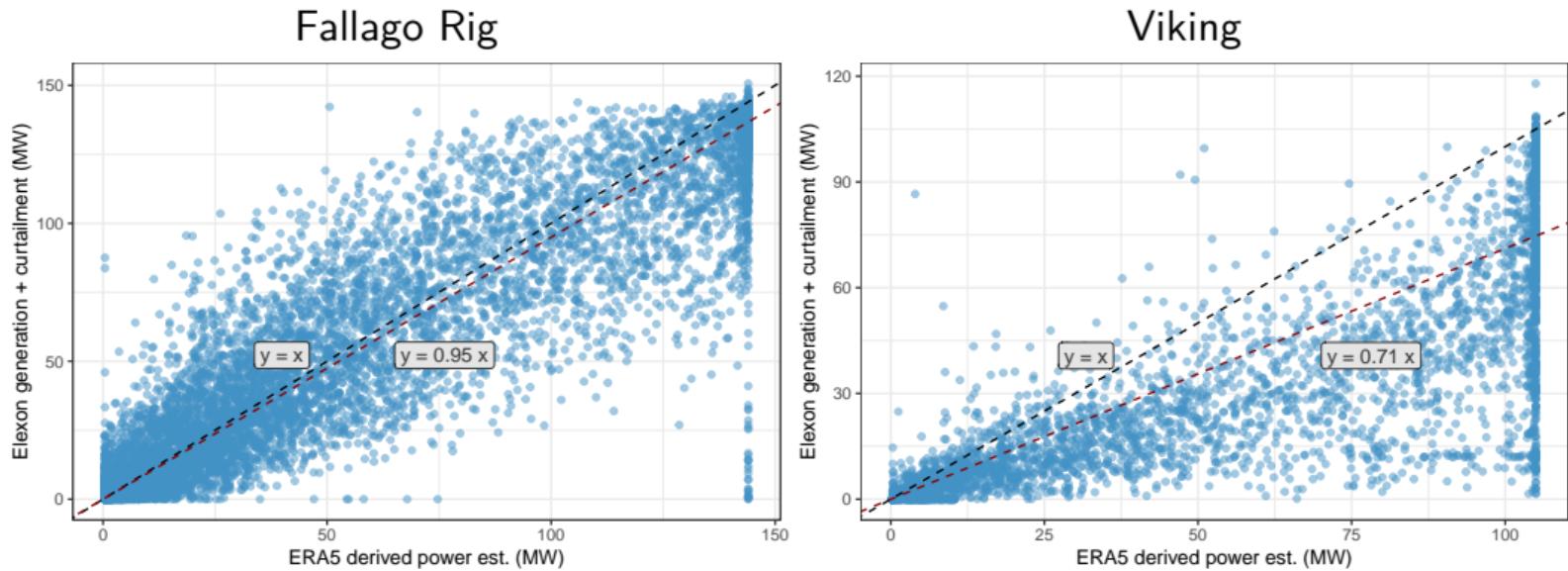


# Generic power curves vs observed data - Seagreen 1

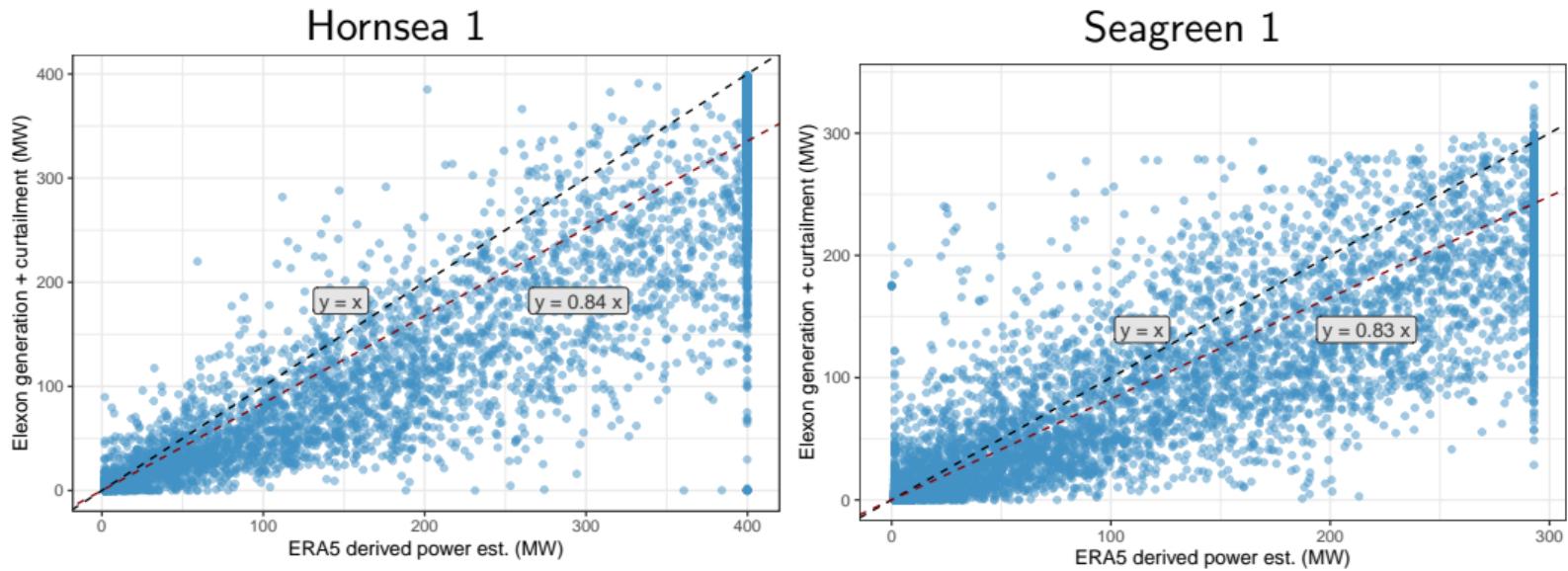
Offshore wind farm with high curtailment



# ERA5 based estimates vs Elexon 2025



# ERA5 based estimates vs Elexon 2025



## Next Steps

- Learn power curve from history
- Quantile mapping calibration