# Accounting for wind-demand dependence when estimating LoLE

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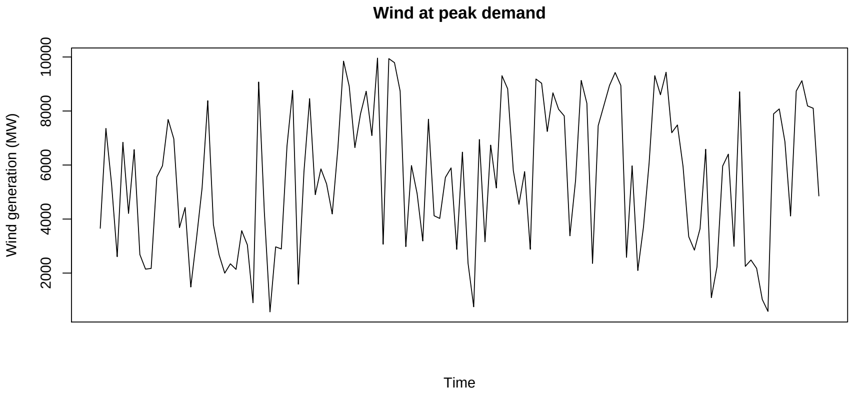
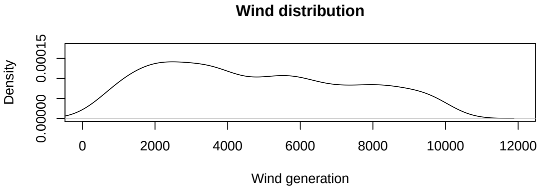
# Wind generation and capacity adequacy

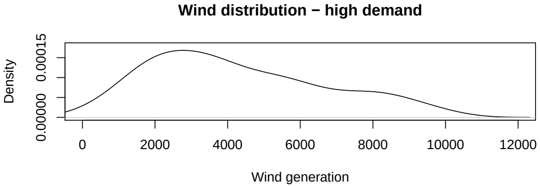
Increasing wind generation in energy systems - will the wind be there when we need it?



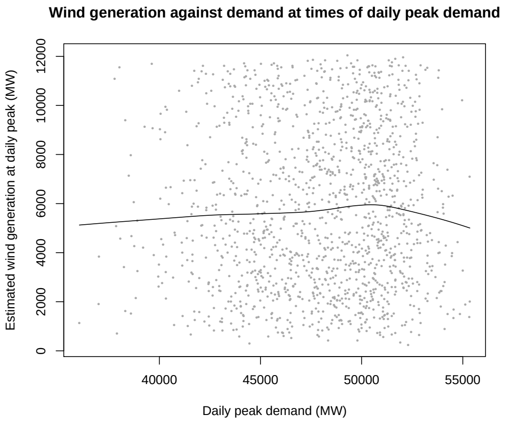
# Demand - wind independence

Current capacity adequacy methods assume conventional generation at a given time is independent of the demand at that time. Holds for wind generation?



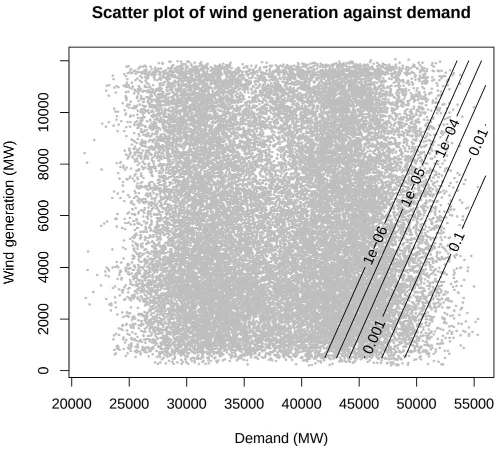



# Demand - wind independence




Model for wind available at a given demand level is required.

# Wind as negative demand (hindcast)



# Non-sequential vs. sequential

Full sequential joint model for **demand**, **conventional generation** and **variable generation**:

- Accounts for correlations through time,
- Model extra aspects of the system such as time to repair,
- Allows for inter-dependencies that change through time,
- More complete picture of capacity adequacy - e.g. probability distribution for size of shortfall.
- Can incorporate storage and flexibility.

For now, as we only looked at LoLE, focus on time-collapsed (non-sequential) model.

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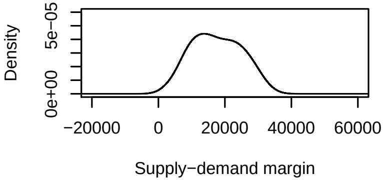
# Data

- Ten years of hourly historical demand data over the peak season, rescaled to a particular future scenario.
- Ten years of corresponding historical wind speed observations, mapped to wind generation under a future scenario.
- Size of conventional generating units, with availability probabilities.

Aim: To model the net-demand, without assuming independence between demand and wind and to calculate the LoLE using this model.

# Capacity adequacy

- LoLP: $P(D - X - W > 0)$, for $D$ =demand, $X$ =conventional generation and $W$ =wind.
- LoLP is generally small. Estimating it requires knowledge about the tail of the distribution of the supply-demand balance $(D - X - W)$.



# Hindcast methodology

$$\text{LoLP} = \frac{1}{n}\sum_{t=1}^{n} P(X \leq d_t - w_t),$$

for observed wind-demand pairs $(d_t, w_t)$.

- Hindcast makes no assumption on the form of the distribution of $D - W$.
- There are few observations in the tail of $D - W$ (high demand and low wind).
- Hindcast estimates will depend heavily on these few observations
- The most extreme possible value of net-demand is assumed to be the most extreme *observation* of net-demand.

# EVT methodology

- Extreme Value Theory (EVT) is a way to smooth the tail of the distribution of $D - W$.
- Above some threshold, $u$, assume that demand-net-of-wind has a distribution function $H$ given approximately by

$$H(y) = P(Y \leq y) = 1 - \left(1 + \frac{\psi y}{\sigma_u}\right)^{-1/\psi},$$

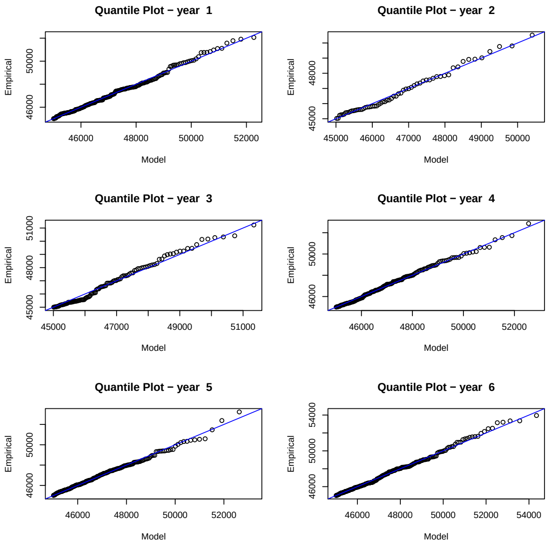
where $y > 0$ and $1 + \psi y / \sigma_u > 0$.

- Below the threshold $u$, use empirical distribution.
- The threshold, $u$, must be chosen. The parameters $\psi$ and $\sigma_u$ are found by fitting the model to the data in the tail.
- Need to validate the fit of this model to the data.

# EVT methodology

- Found that results were robust to choice of threshold (thresholds from 42GW to 48GW gave roughly same answers). We chose 45GW.
- Fitted model using maximum likelihood.
- Validated the model using quantile plots. These compare 'observed' demand-net-of-wind values to the 'idealised' values using the EVT approach. Would expect a straight line.

# EVT validation



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# Estimating the LOLE

Use model to estimate LoLE:

$$nP(D_t - W_t > X_t),$$

$D_t$ =demand (time t), $W_t$ =wind (time t), $X_t$ =conventional generation, $n$ =time periods under study.

- Use EVT method to get discrete approximation of distribution of net-demand (i.e. $D_t - W_t$).
- Convolve with distribution of conventional generation (two state model) to get distribution of $D_t - W_t - X_t$.
- Get LoLE $= nP(D_t - W_t - X_t > 0)$.

# Uncertainty

- Demand and wind are uncertain, so LoLE should be presented with uncertainty bounds.
- Data are complicated - seasonal effects, daily effects, holiday periods, serial correlation - so difficult to do.
- Get around this by conditioning on individual years. That is, fit distribution to $D - W$ using each of the ten years separately, to get ten different LoLEs.
- The ten LoLEs represent variability in demand and wind.
- Can fit t-distribution to the ten LoLEs to give a rough confidence interval.

| Scenario | LOLE EVT | Hindcast | Ind |
|---|---|---|---|
| SP 15/16 | 10.71 | 10.52 | 9.81 |
| SP 16/17 | 12.33 | 12.20 | 11.41 |
| SP 17/18 | 4.24 | 4.21 | 3.68 |
| NP 15/16 | 6.30 | 6.21 | 5.63 |
| NP 16/17 | 17.18 | 16.83 | 15.94 |
| NP 17/18 | 3.43 | 3.46 | 2.98 |

Table: LOLE estimated using the full dataset for three different estimation methods

| Scenario | | EVT | Hindcast | Independence |
|---|---|---|---|---|
| SP 15/16 | Mean | 10.41 | 10.52 | 10.61 |
| | CI | (5.42,15.41) | (5.44,15.61) | (5.8,15.41) |
| SP 16/17 | Mean | 12.10 | 12.20 | 12.31 |
| | CI | (6.36,17.84) | (6.42,17.97) | (6.88,17.73) |
| SP 17/18 | Mean | 4.10 | 4.21 | 4.10 |
| | CI | (1.65,6.56) | (1.61,6.81) | (1.94,6.25) |
| NP 15/16 | Mean | 6.07 | 6.21 | 6.18 |
| | CI | (2.83,9.31) | (2.83,9.6) | (3.1,9.27) |
| NP 16/17 | Mean | 16.87 | 16.83 | 17.04 |
| | CI | (9.42,24.33) | (9.43,24.24) | (9.93,24.15) |
| NP 17/18 | Mean | 3.31 | 3.46 | 3.34 |
| | CI | (1.24,5.38) | (1.22,5.7) | (1.51,5.16) |

Table: Confidence intervals (CI) for the mean LOLE calculated using the four different estimation methods

# Surprising result

- EVT and independence results almost identical when we condition on individual years.
- But not when we estimate LoLE using full dataset (traditional method - estimate distribution of wind using ten years of data).
- Could be underlying ‘year effect’ - i.e. demand and wind are correlated due to an underlying seasonal weather pattern.
- By conditioning on individual years, we eliminate the correlation.
- So may be better to estimate LoLE by taking mean of ten LoLEs than to calculate in one go using full dataset.

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# Conclusion

- EVT has benefit of hindcast (accounts for demand-wind correlation).
- But also resolves some of the downsides (smooths the tail and has a non-zero probability for events more extreme than those observed).
- Results fairly similar to hindcast with current dataset, but risk that when looking further into the tail problems with hindcast may become more apparent.
- In GB, a lot of wind-demand correlation seems to be explained by conditioning on year ('year effect').
- Better to estimate LoLE by conditioning on individual years? Can also get uncertainty bounds this way.

With thanks to National Grid