Sequential modelling of variable generation for capacity adequacy assessment

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Capacity adequacy studies

- Electricity generating plants take many years to build.
- Risk of insufficient supply to meet demand must be assessed many years in advance so that action can be taken.
- GB has an annual 'capacity assessment study' looking at risk of shortage of supply.
- Study informs how much capacity to procure in Capacity Market Auction (worth $\sim$ £1bn per year).
- Consultant to National Grid (NG) on statistical methodology for this study, 2014 - present.

Statistical problem

- Current risk metric in GB is hourly Loss of Load Expectation (LoLE):

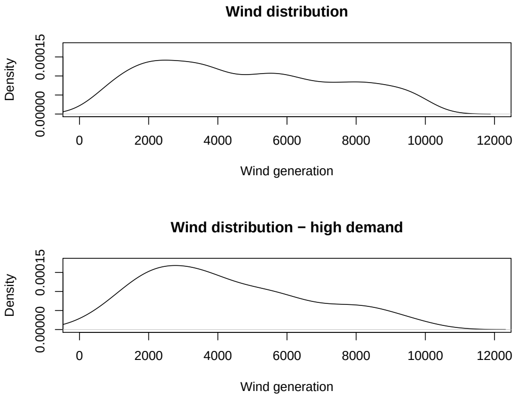
$$\sum_{t=1}^{n} P(D_t > X_t + W_t),$$

for D_t =demand in hour t, X_t =supply in hour t from conventional generators (e.g. gas, coal, nuclear), W_t =wind generation in hour t.

- Joint model needed for D_t, X_t and W_t.
- Current methods are 'time-collapsed' - only look at expected value indices like LoLE. For full picture of risk need sequential model.

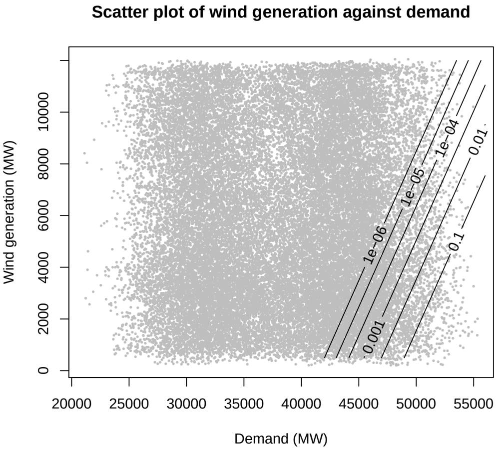
Wind/demand dependence

Wind is thought to drop at very low temperatures (i.e. high demand). Not modelling this could underestimate shortfalls



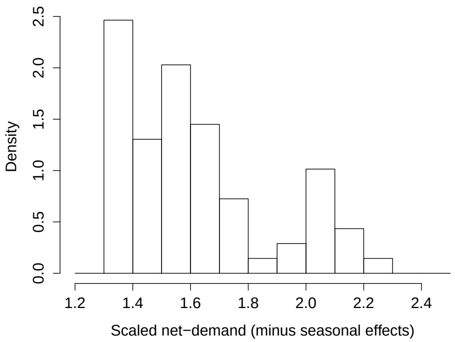
Limited data

One solution posed is to use empirical distribution for $D - W$.



Smoothing

Parametric model in tail can smooth data. Extreme value theory provides asymptotic theory for this smoothing.



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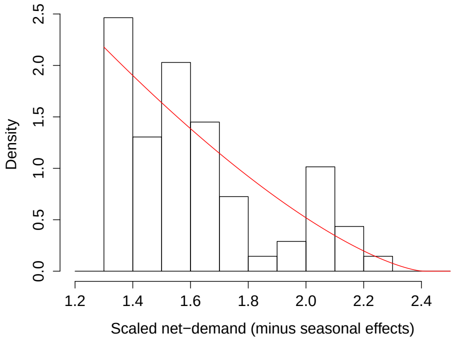
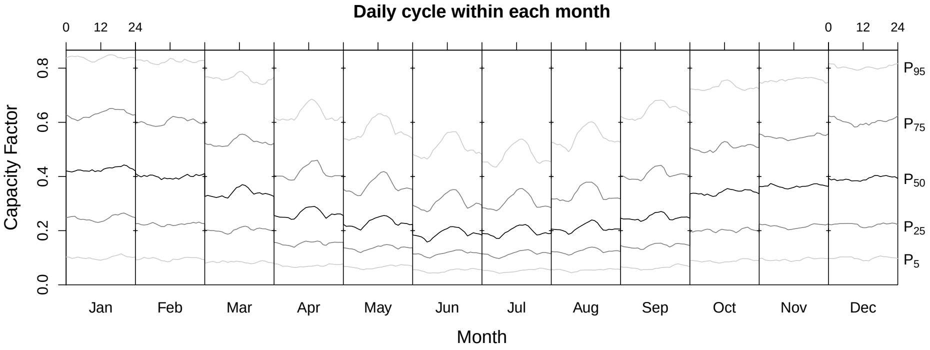


Data

- 8 years of hourly demand data, re-scaled to future year/scenario. Includes distributed generation.
- Capacities, availability probabilities and mean times to repair for all conventional generating plants in future year/scenario.
- 8 years of hourly wind generation 'data'. Formed from wind speed reanalysis data (MERRA) combined with model for wind farms in place in future year/scenario.

Ultimate aim: develop a sequential hourly joint model for demand and renewable generation. Currently have daily model for net-demand at time of peak demand.

Seasonal effects



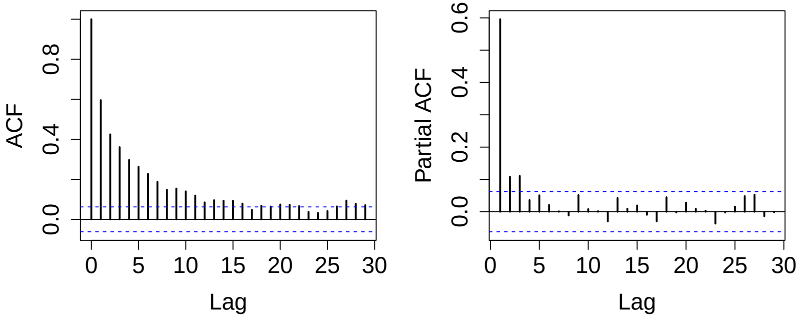
Seasonal effects

Linear regression used to capture seasonal effects in wind and demand series.

- Demand explanatory variables (adjusted $R^2 = 0.8271$):
    - Time of year (Fourier series),
    - Day of week.
- Wind explanatory variables (adjusted $R^2 = 0.015$):
    - Time of year (Fourier series).

Used these regression models to filter out seasonal effects. Then modelled net-demand after filtering out effects (residual net-demand r_t).

Autocorrelation



Correlation in residual process (r_t) at varying time lags.

EVT - marginal distribution

- Extreme Value Theory (EVT) used to model tail of marginal distribution of residual net-demand r_t.
- Assume that excesses of net-demand residuals above some threshold u (conditional on $R_t > u$), have distribution function (GPD):

$$P(R_t - u > r \mid R_t > u) = \left(1 + \frac{\psi r}{\sigma_u}\right)_+^{-1/\psi},$$

  where $r \geq 0$.
- Below the threshold u - empirical distribution.
- Threshold, u, must be chosen. Parameters ψ and σ_u are found by fitting the model to the data in the tail.

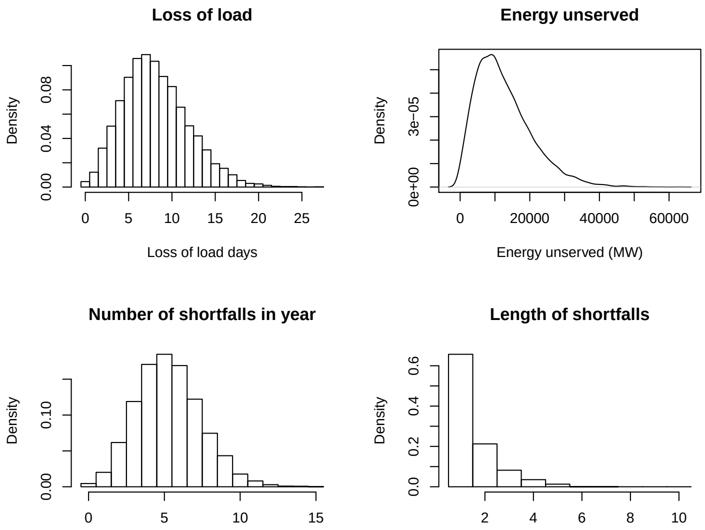
Model for extreme dependence

- Winter/ Tawn approach
  Winter, HC, and Tawn, JA. *Modelling heatwaves in central France: a case-study in extremal dependence.* RSS: Series C 65(3), 2016, p345–365.
- Transform so marginal distribution is Laplace.
- Model conditional dependence as:

$$T(R_{t+1}) = \alpha T(R_t) + T(R_t)^{\beta} Z_{t+1},$$

  for $T(R_t) > T(u)$, where $T(\cdot)$ represents Laplace transformation, $Z_{t+1} \sim G$, Z_{t+1} is iid and independent of R_t, $\alpha \in (-1, 1)$, $\beta \in (-\infty, 1)$.
- If $\alpha = \beta = 0$, implies independence. If $\alpha = 1, \beta = 0$ implies asymptotic dependence.

Results for example year



Empirical results (expected value)

Historic year	Empirical results	
	LoLE (h)	EEU (MWh)
2007–08	5.26	6,675
2008–09	5.46	7,119
2009–10	8.72	12,994
2010–11	14.04	26,509
2011–12	3.91	5,446
2012–13	10.73	17,313
2013–14	1.08	942
Overall	7.03	11,000

Conclusion and next steps

- Have sequential model for net-demand at time of daily peak demand. Methodology more widely applicable. Plan to extend to hourly model.
- For hourly model, need to model more complex seasonal effects,
- Could incorporate meteorological variables in the analysis (temperature, North Atlantic oscillation) to explain seasonal effects,
- Use same techniques to include solar generation in the analysis.

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