# DEL Quarterly Seminar Feb'14

Presentation: Forecasting peak gas consumption for year-ahead gas network management.

PhD: Analysis of domestic and SME gas consumption in Ireland - implications for a competitive, low-carbon economy.

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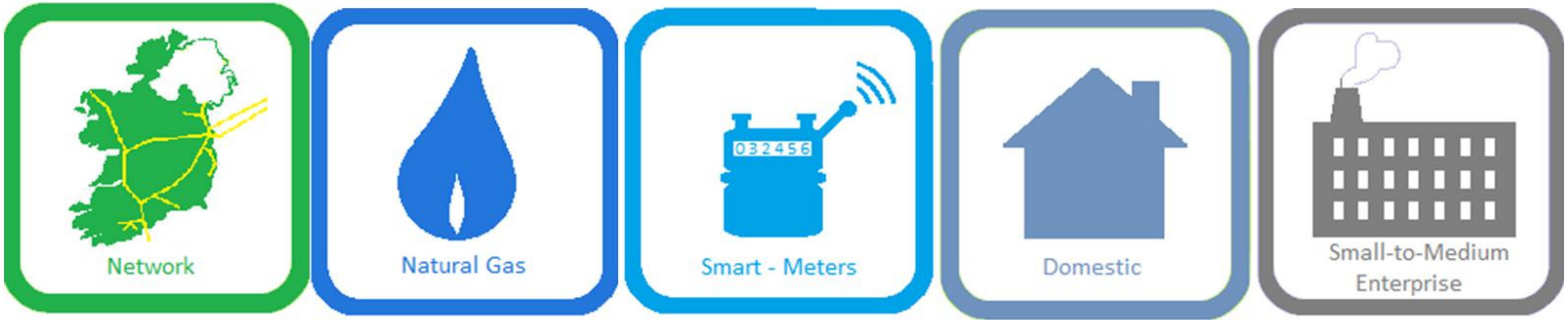


# Peak Gas Consumption (1)

- Objective: Develop statistical models to forecast year-ahead peak gas consumption for the Irish domestic and SME (or non-daily metered) gas market.

- Peak Gas Consumption?
  - Estimate of gas consumption under extreme weather conditions using a model of current gas consumption and a historical climate dataset.
- Motivation:
  - Forecasts can be used to ensure sufficient supply and reserve capacity of gas on the network, should extreme weather conditions occur.
  - Recently two extremely cold winters have occurred: Jan’ & Dec’ 2010; however, current estimators of gas consumption assume linear consumption during winter-time,
  - Solar radiation: recent studies suggest that this is an important estimator of gas consumption.
- Non-daily metered (NDM) gas market:
  - 630k+ domestic and 30k+ SME gas consumers, comprising 66% and 33% of NDM gas consumption, respectively,
  - These consumers account for the majority of supply points connected to the gas distribution network,
  - Domestic gas consumers – including a proportion of SMEs – are ‘protected’ under EU Regulations.

# Peak Gas Consumption (2)

- BGN estimate peak daily gas consumption for **1-in-50 year extreme weather conditions.**

- EU Regulation No. 994 (2010) concerning measures to safeguard security of gas supply:
  - Article 8:

    Supply standard – to protected consumers

    (a) extreme temperatures during a **7-day peak period** occurring with a statistical probability of **once in 20 years**;

    (b) any period of at least 30 days of exceptionally high gas demand, occurring with a statistical probability of once in 20 years; and

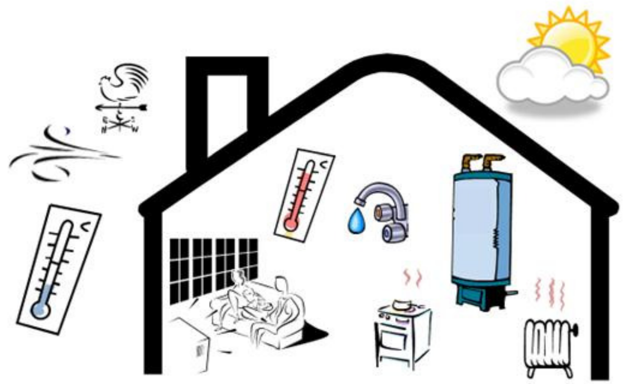
    (c) for a period of at least 30 days in case of the disruption of the single largest gas infrastructure under average winter conditions.

- **Supply Capacity**: 1-in-50 year daily gas consumption requirement.
- **Reserve Capacity**: 1-in-20 year 7-day gas consumption requirement.

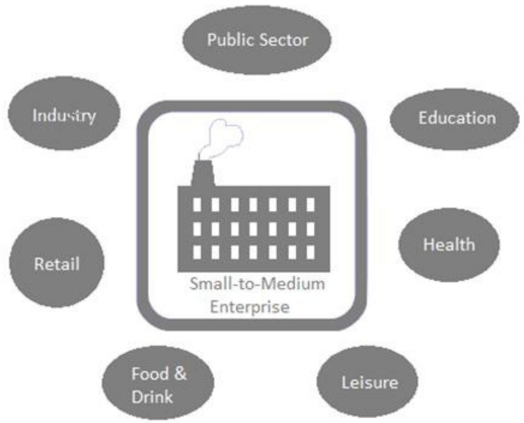
# Data

- NDM data since Oct'05:
  - Daily gas consumption,
  - Monthly consumer numbers.

- Climate data:
  - Dublin airport,
  - Daily temperatures and wind-speeds since 1941,
  - Daily solar radiation values since 1976.



- Economic indicator:
  - Monthly retail sales index,
  - If required, this is used to account for changed economic activity amongst NDM consumers over time.



# Extreme Value Modelling

- Predict daily NDM gas consumption, using:
  - current model of consumption, and
  - NDD calculated for each day in the available climate dataset.

- Record Block Maxima series, i.e.:
  - Supply capacity: maximum predicted consumption value for each gas year, for 1-in-50 daily consumption estimation; or
  - Reserve capacity: maximum 7 day cumulative predicted consumption value for each gas year, for 7-day 1-in-20 consumption estimation.

- Estimate GEV model

- Estimate Gumbel model

- Compare Goodness of Fit

- Estimate the required 1-in- 20 or 50 return levels using the most representative extreme value model type.

# Gas Consumption Modelling (1)

- Gas years: Oct - Sept
- Linear Regression Model:
  - $NDM_D = f$ (Day-Type, Cons' No., RSI, NDD)
    - $NDM_D$=Daily NDM gas consumption,
    - Day-Type = Weekdays, Saturdays, Sundays, Holidays & Christmas,
    - Holidays = Irish public holidays,
    - Christmas = $24^{th}$ Dec' – $1^{st}$ Jan, or
      = $24^{th}$ Dec' – $2^{nd}$ Jan for $25^{th}$ = Sunday, or
      = $24^{th}$ Dec' – $3^{rd}$ Jan for $25^{th}$ = Saturday,
    - Cons' No. = Consumer numbers, domestic and SME,
    - RSI = retail sales index,
    - NDD = Network Degree Day.
- Network Degree Day (NDD):
  - NDD = $f$(T, WS, GR; $ES$, $F$, $G$)
    - T, WS & GR = Temperature, Wind-Speed & Global Radiation,
    - $ES$ = exponential smoothing function – to model climate response inertia,
    - $F$ = Fourier function – to model seasonal temperature,
    - $G$ = Gumbel transformation – to model the non-linear gas consumption response.

# Gas Consumption Modelling (2)

**NDD Parameter Estimation**

**Non-linear regression:** Oct'05 – Sept'12: $R^2$=0.9867, MAPE=7.22

$$NDM_D = b_0^{***} + b_{\Delta 0,Sat}^{***} + b_{\Delta 0,Sun}^{***} + b_{\Delta 0,Hol}^{***} + b_{\Delta 0,\mathrm{C'mas}}^{\cdot} + b_{1,Dom}^{***} + b_{2,\mathrm{SME}}^{***} + b_3^{***} NDD_D + b_{\Delta 3,\mathrm{Sat}}^{***} NDD_D + b_{\Delta 4,\mathrm{Sun}}^{***} NDD_D + b_{\Delta 4,\mathrm{C'mas}}^{***} NDD_D$$

*NDD* nonlinear parameters: all significant to '***' $p < 0.001$ level.

**Current Model of Gas Consumption**

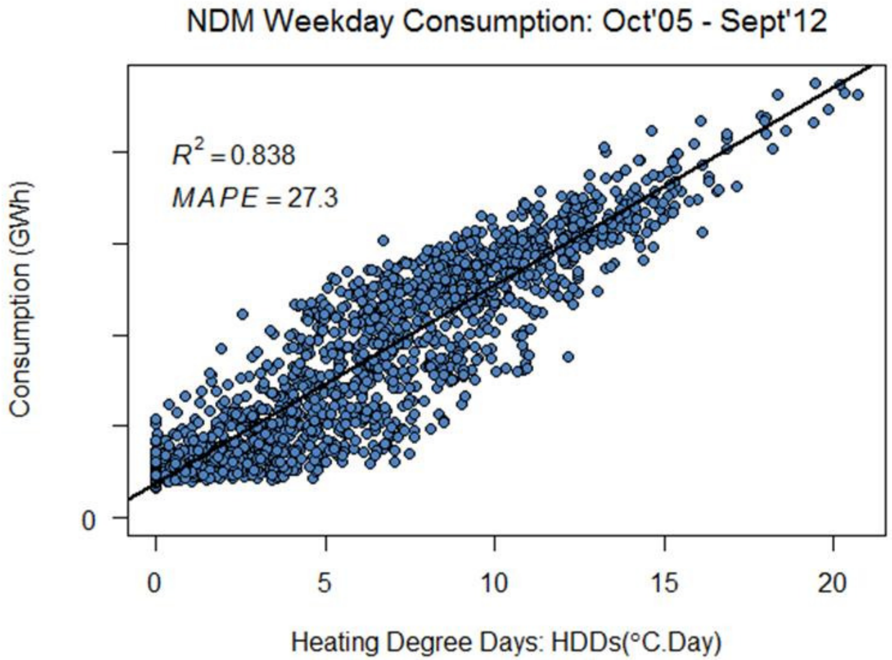
**Linear regression:** Oct'10 – Sept'12: $R^2$=0.9841, MAPE=7.7

$$NDM_D = b_0^{***} + b_{\Delta 0,Sat}^{\cdot} + b_{\Delta 0,Sun}^{*} + b_{\Delta 0,Hol}^{**} + b_3^{***} NDD_D + b_{\Delta 3,\mathrm{Sat}}^{***} NDD_D + b_{\Delta 4,\mathrm{Sun}}^{***} NDD_D + b_{\Delta 4,\mathrm{C'mas}}^{***} NDD_D$$

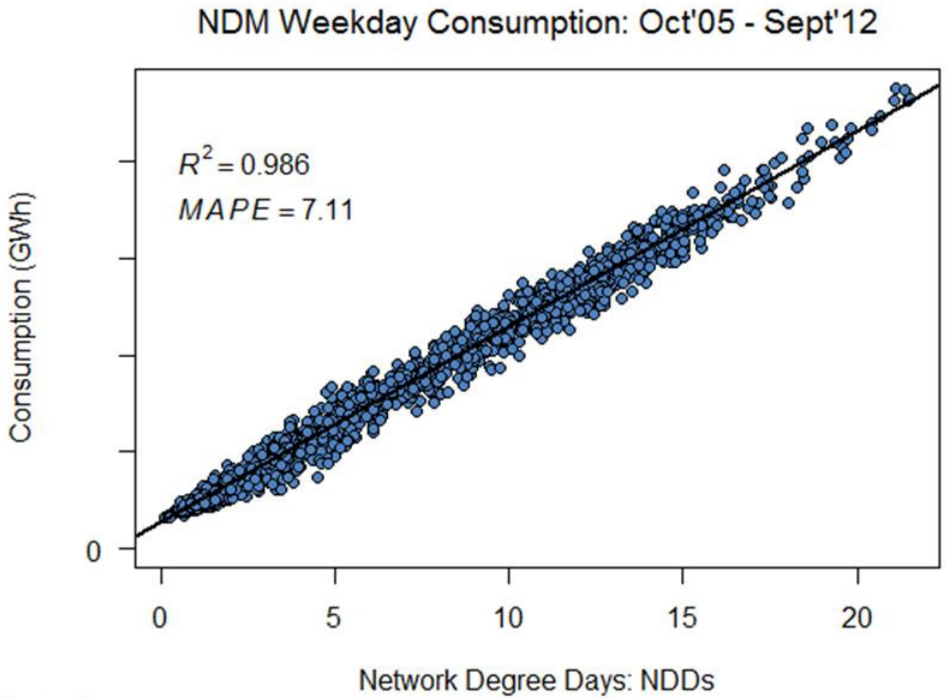
Sig' Levels: '·' $p < 0.1$, '*' $p < 0.05$, '**' $p < 0.01$, '***' $p < 0.001$.

MAPE = 8.2, for this period for the initial model.

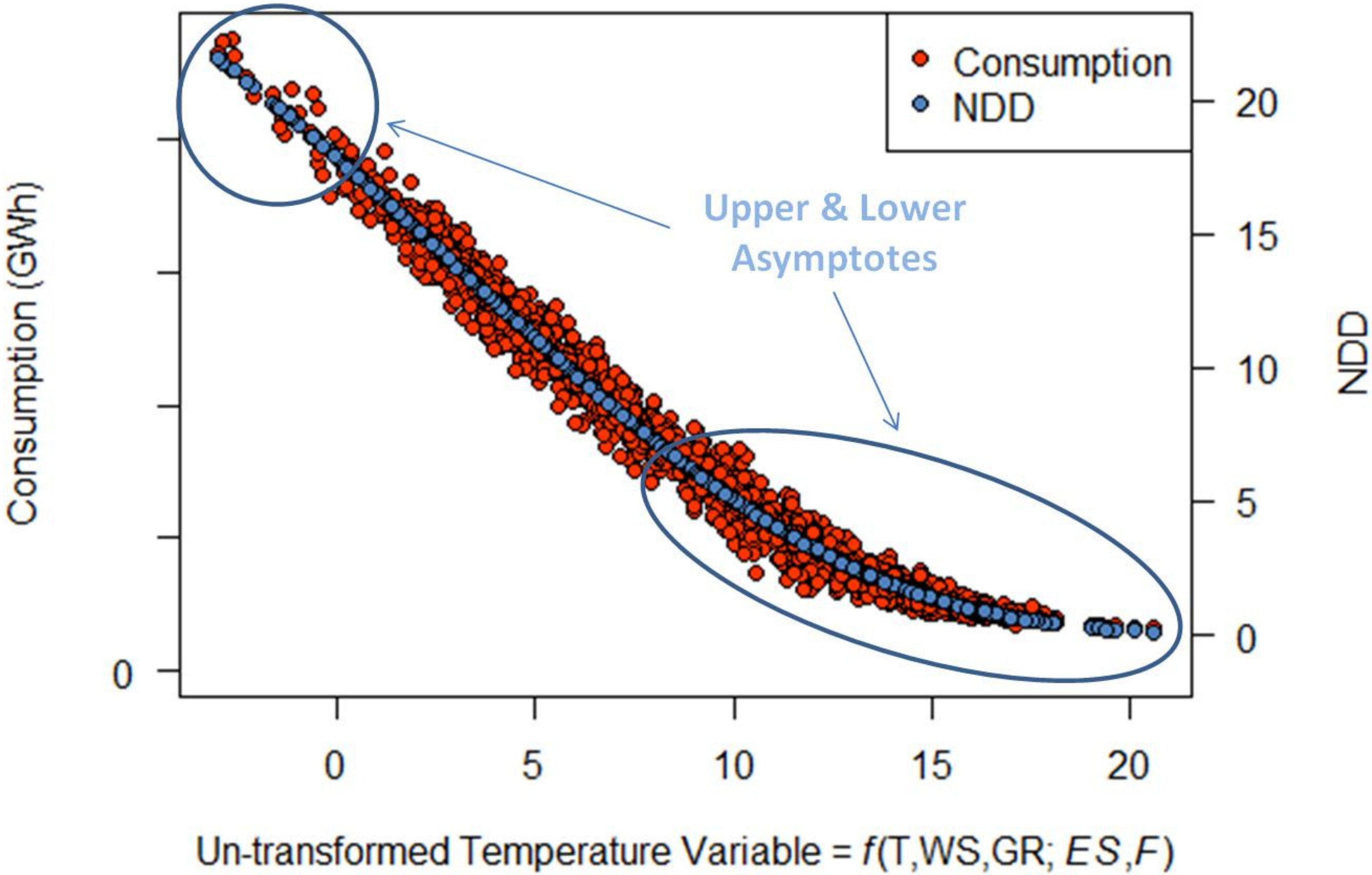
# HDD vs. NDD



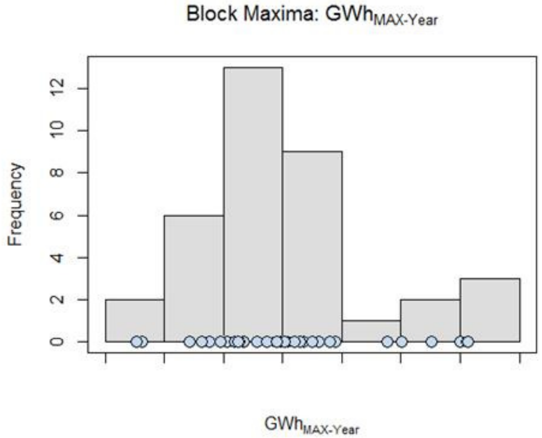

- MAPE=10.3, if Global Radiation is omitted from NDD function



# NDD: Gumbel Transformation

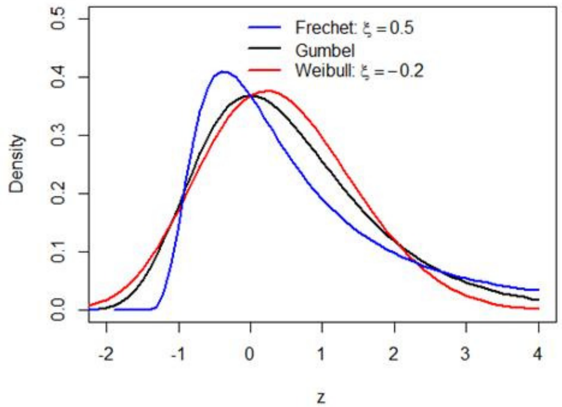


# Block Maxima: Extreme Value Model




$$GEV(z;\ \mu, \sigma, \xi) = \begin{cases} exp\left\{-\left[1+\xi\left(\frac{z-\mu}{\sigma}\right)\right]^{-1/\xi}\right\}, \text{for } \xi \neq 0 \\ exp\left\{-exp\left[-\left(\frac{z-\mu}{\sigma}\right)\right]\right\}, \text{for } \xi = 0 \end{cases}$$

where, $z$ is the data series, $\mu$, $\sigma$, and $\xi$ are the location, scale and shape parameters




and $z$ return level ($z_p$) for the a given return period (1/$P$), and $p$ = 1/$P$ years:

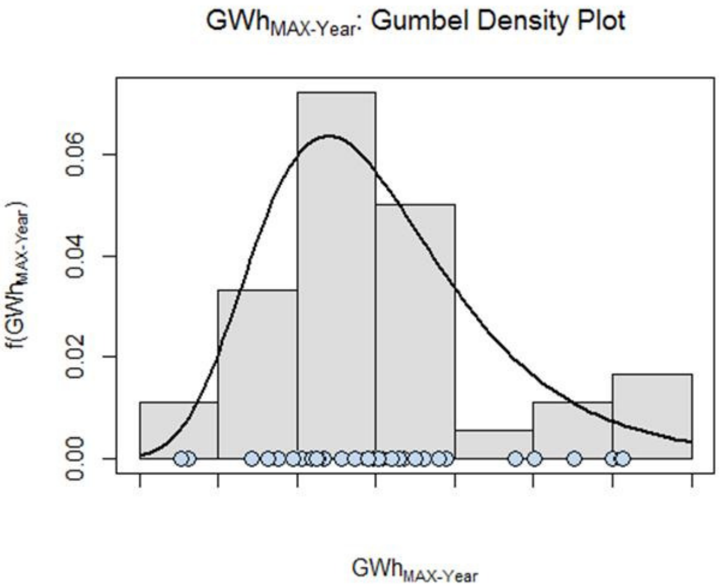
$$z_P = \begin{cases} \mu - \frac{\sigma}{\xi}\left[1-\{-log_e(1-p)\}^{-\xi}\right], & for\ \xi \neq 0, \\ \mu - \sigma log_e\{-log_e(1-p)\}, & for\ \xi = 0. \end{cases}$$

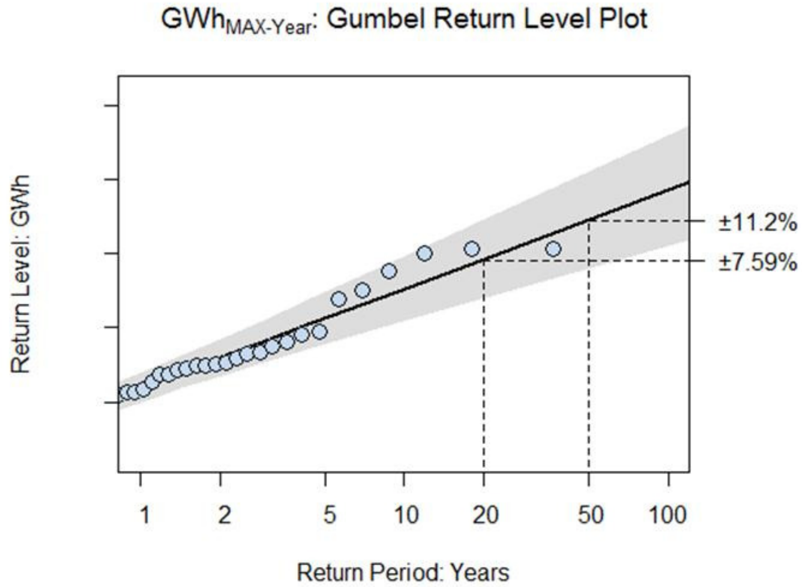
Modified Anderson-Darling Upper-Tail Test:

$$AU_n^2 = \frac{n}{2} - 2\sum_{i=1}^{n} F(x_i) - \sum_{i=1}^{n}\left\{2 - \frac{2i-1}{n}\right\} log\{1 - F(x_i)\}$$

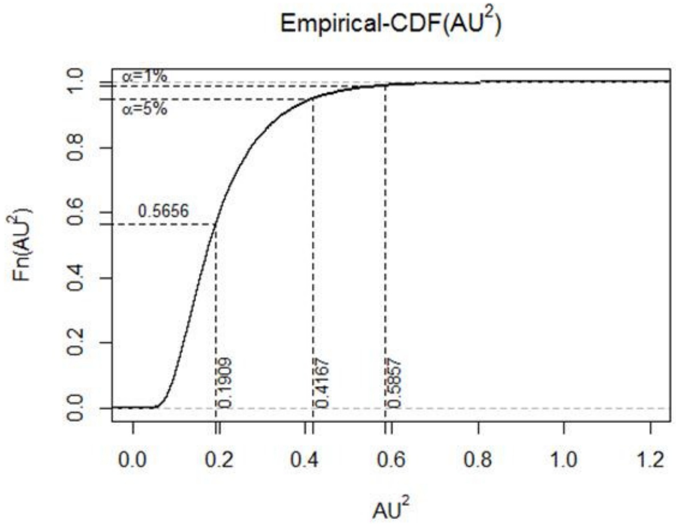
The Modified-Anderson Darling statistic is a test as to whether a data series comes from the hypothesised distribution *F(x)*, using a weighting function that gives greater emphasis to deviations at the upper tail of the distribution.

# Supply Capacity – GEV: 1-in-50 year

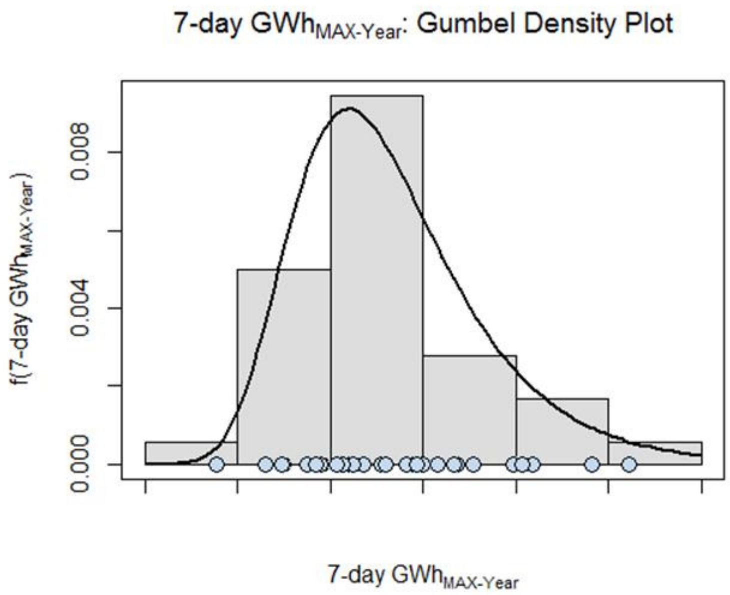


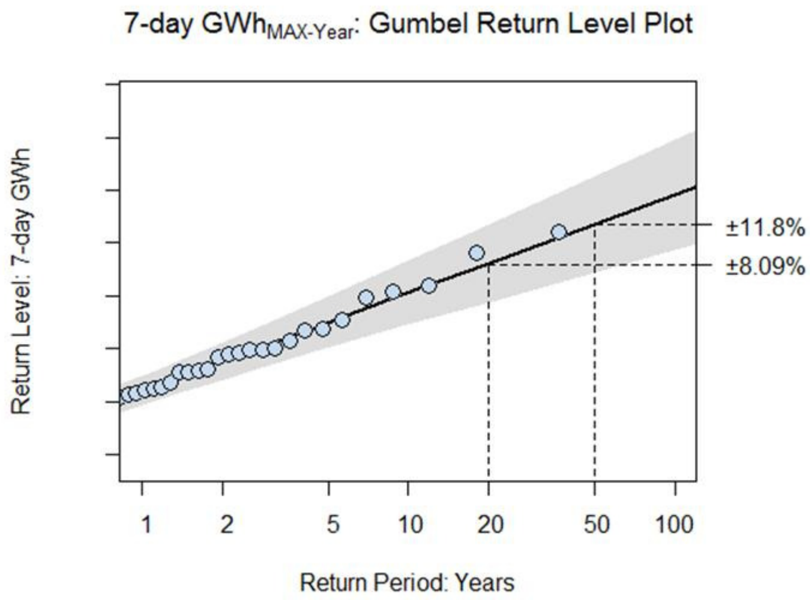




- GEV simplified to a Gumbel CDF due to insignificant GEV shape parameter and an improved goodness of fit result – 0.1902 vs. 0.2504
- Gumbel CDF passes Modified-AD test.
- Goodness of fit result for a simplified NDD (i.e. no GR and data since 1942) shows little improvement in GEV model fit.

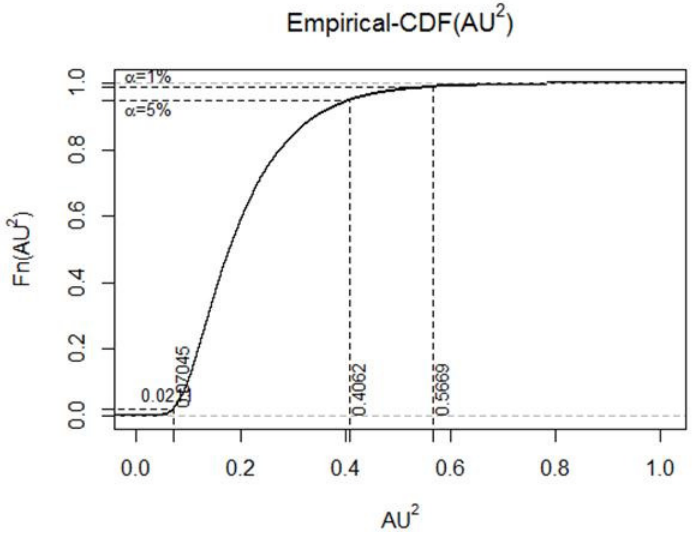


# Reserve Capacity – GEV: 7-Day 1-in-20 year




- Again, GEV simplified to a Gumbel CDF due to insignificant GEV shape parameter and an improved goodness of fit result – 0.07045 vs. 0.08315.
- Excellent Modified-AD test result.



# Questions