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Modelling future generation portfolios under electricity industry uncertainties and multiple objectives

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Monte **C**arlo **Elect**ricity Generation Portfolio Modelling Tool (MC-ELECT)

A probabilistic tool that assesses future generation portfolios against multiple objectives given a range of future uncertainties

- Incorporating key uncertainties and risk assessment into generation investment and planning analysis
- Consider the multiple objectives nature of investment decision-making
- Intended to complement existing electricity industry modelling tools

Facilitating industry policy decision-makers in planning and investment in uncertain future electricity industries

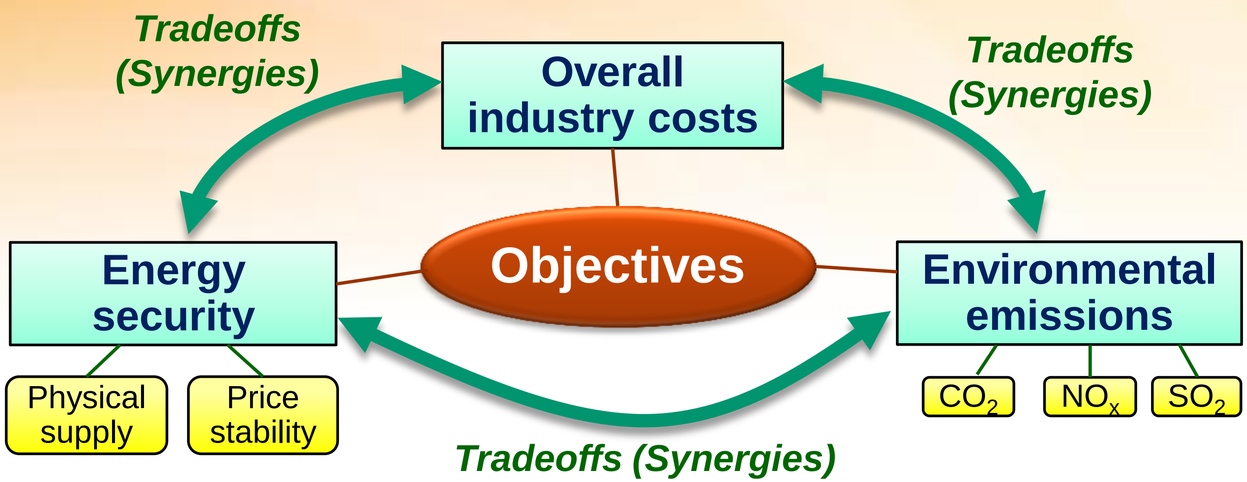
- Provide a basis for comparing future generation portfolios based on particular objectives and preferences (Costs, Cost risks and emissions)
- Quantitative analysis of potential tradeoffs among generation portfolios and multiple objectives

Implemented in MATLAB (source codes are available)

Context and main drivers

What can sensibly be said about future electricity industries?

- Significant uncertainties (and hence risk) in the electricity industry
- Multi-objective nature (economic, environment, energy security)



Potential conflicts between these objectives in many countries

Different generation options with different characteristics

- Coal generation – cheap to run but high emissions.
- Gas-fired - energy security concerns (due to fuel import) but low emissions.
- Renewables – High fixed cost at present and highly variable but no emissions.

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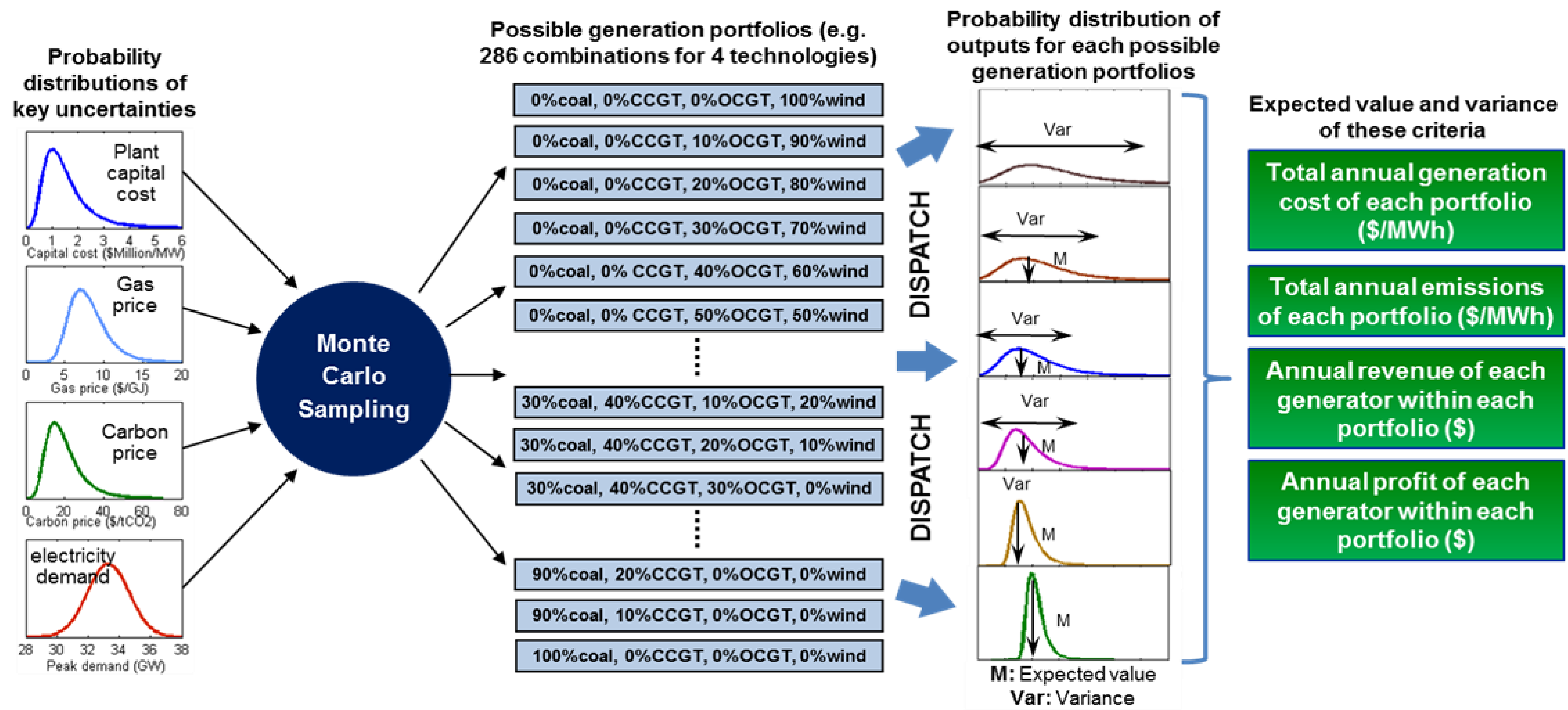
Key techniques used in the model

- Extends the commonly applied Load Duration Curve techniques
- Incorporating uncertainty into key cost assumptions using Monte Carlo simulation techniques (e.g. fossil fuel prices, carbon price, demand)
  - All of the outputs can be represented by a series of prob. distributions

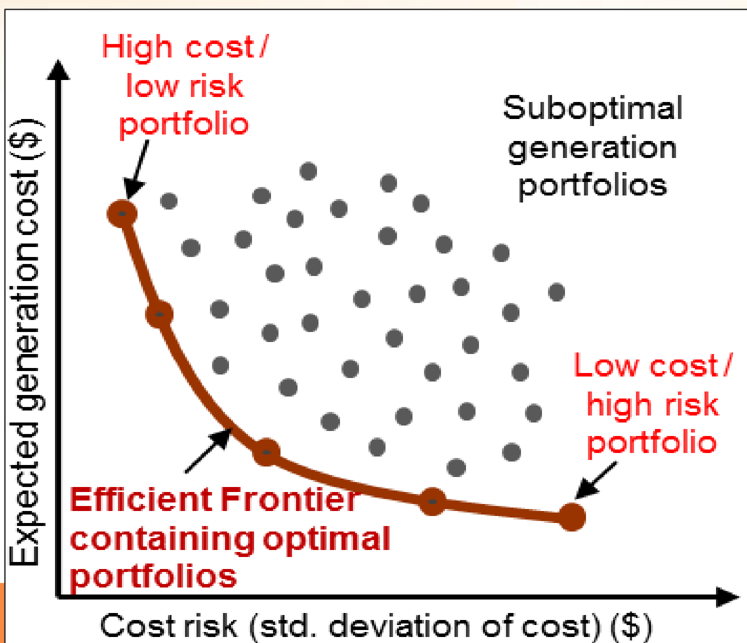


Key techniques used in the model

- MCS is a comprehensive yet flexible method for analysing problems which involve many, and interacting uncertainties.

MCS process

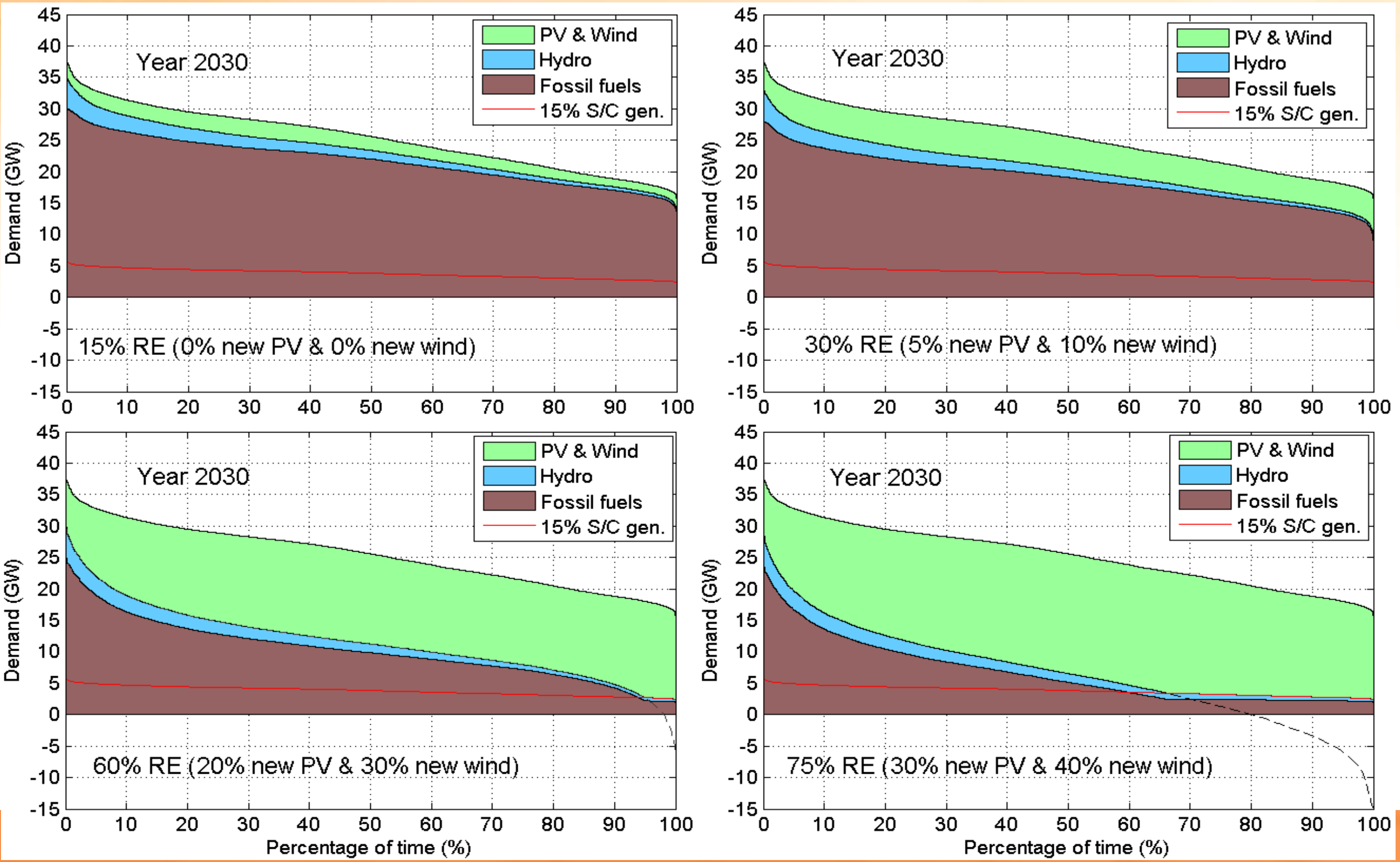
Identify uncertain variables → Assign probability distributions to uncertain variables → Define correlation among uncertain variables → Method to generate random samples → Simulation runs (i = n samples) → Possible results represented by a probability distribution



- Model outputs can be used to explore various issues and tradeoffs between multiple criteria - *costs, cost risks (SD of costs) and emissions*
- Optimal generation portfolios fall along ***"Efficient Frontier"*** *(Costs can only be reduced by accepting higher cost risks (or emissions).*

Generation dispatch

- SRMC bidding, merit order dispatch (30 minute or hourly).
- Priority dispatch for renewable generation – *Residual load duration curve.*
- Applying a *"minimum synchronous generation"* constraint



Annual costs ($/MWh) = Annualised fixed costs + Variable costs

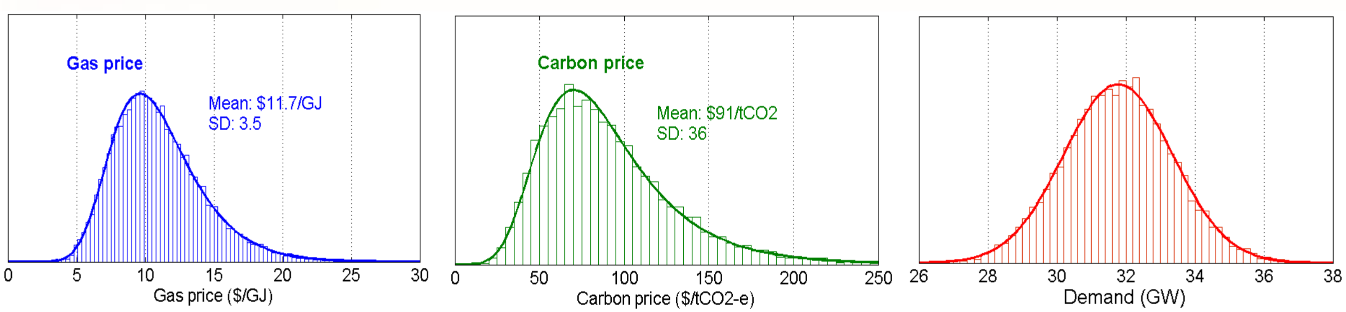
Example of Load duration Curves for different renewable penetrations

Modelling inputs

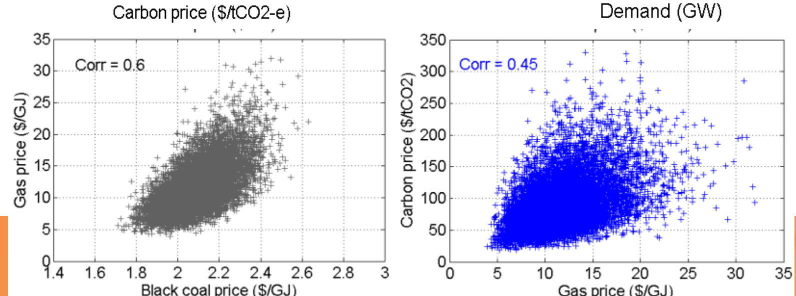
Inputs

- **Generator characteristics of each technology**
  Plant life, cost parameters, Emission factors, operating parameters
- **Hourly demand, RE gen. output in a future year**
- **Prob. distributions of uncertain parameters**
  Fuel prices, carbon price, electricity demand, plant capital costs

- Probability distributions of uncertain variables and their correlations can be determined based on historical trends or expert judgments



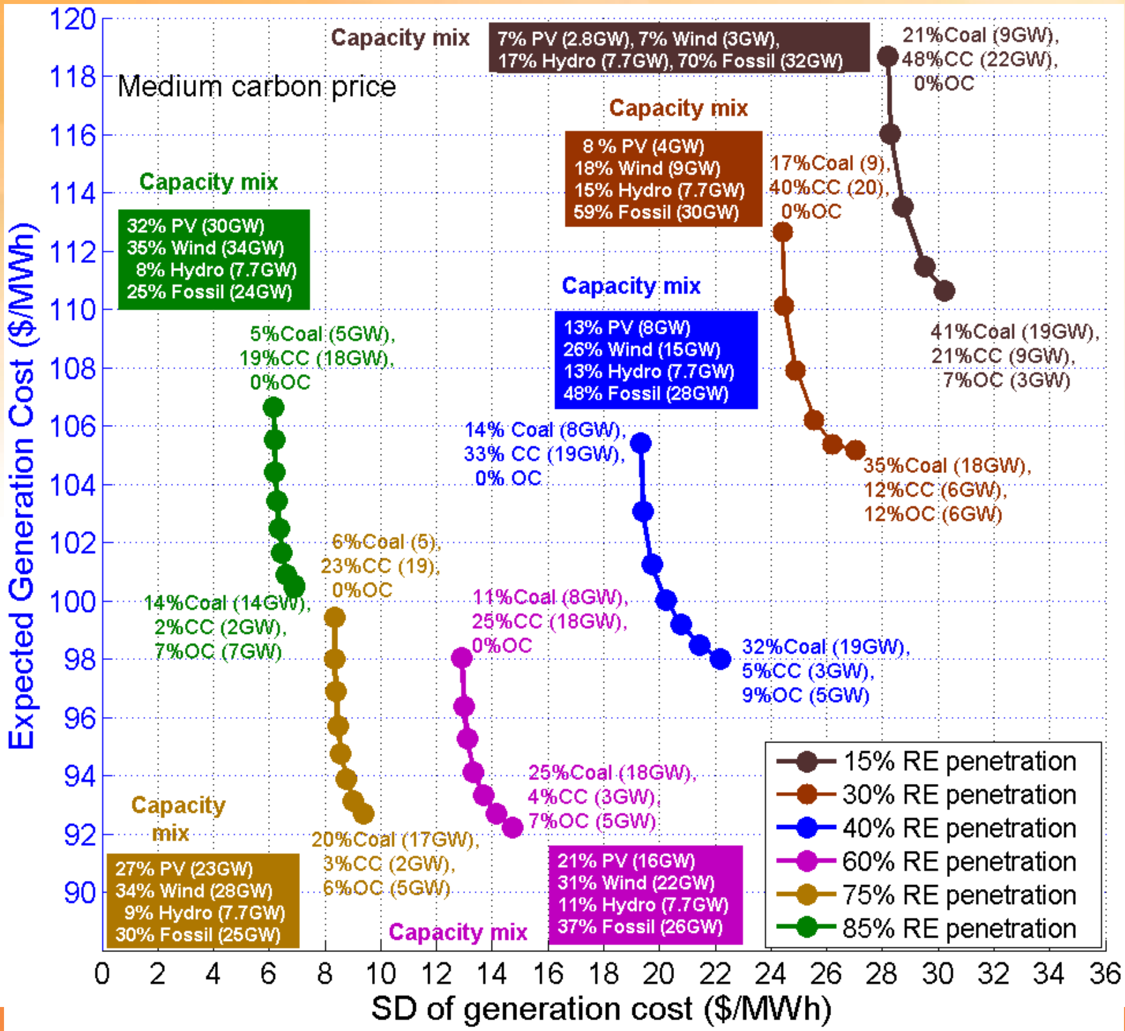
Prob. Distribution of fuel and carbon price and peak demand over *N* simulations



Scatter plot showing the correlation

Outputs – Cost vs risk tradeoffs

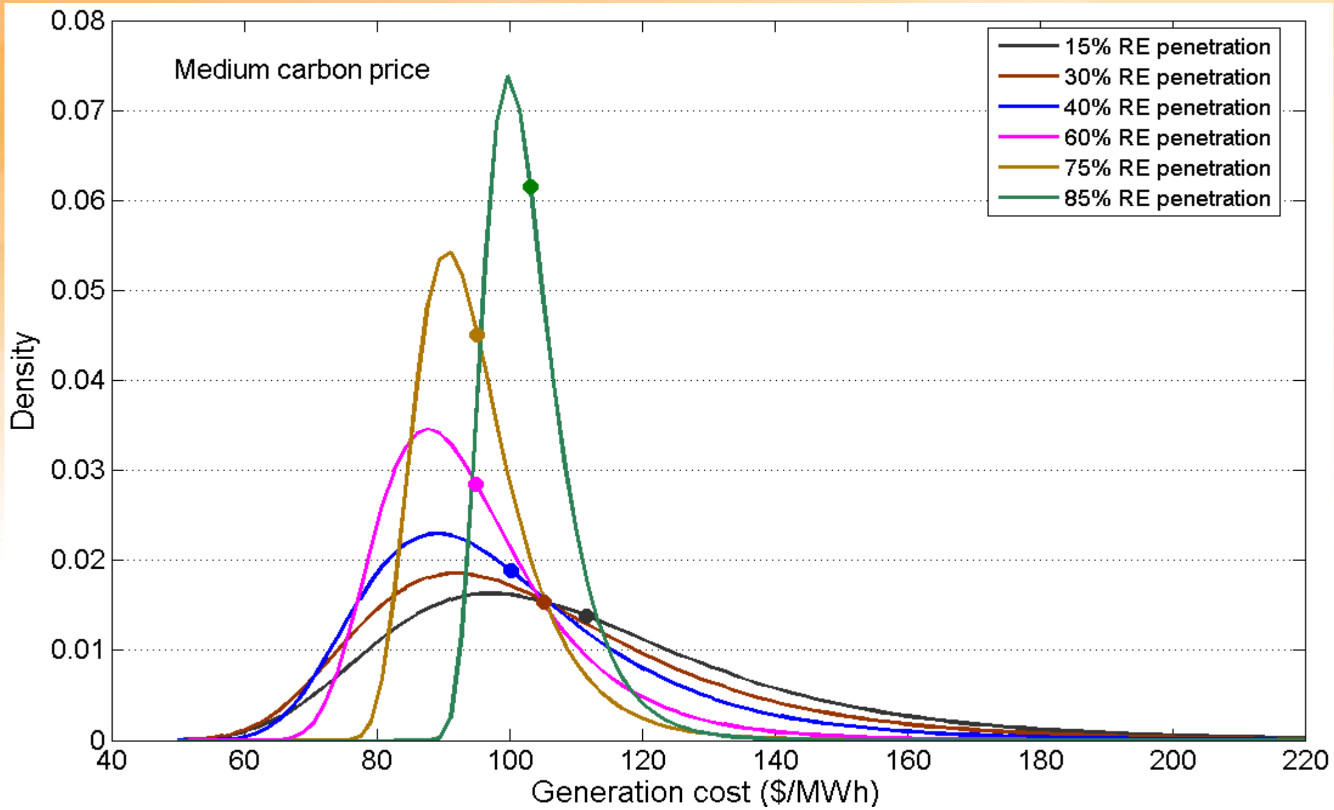
Results from a case study of the Australian NEM with high renewables



‘Cost VS Cost risk Efficient Frontier’ (EF) for each RE penetration

- *Expected cost (mean)* and *cost risk (SD of cost)* of generation portfolios on the ‘Efficient Frontier’ (optimal generation portfolios)

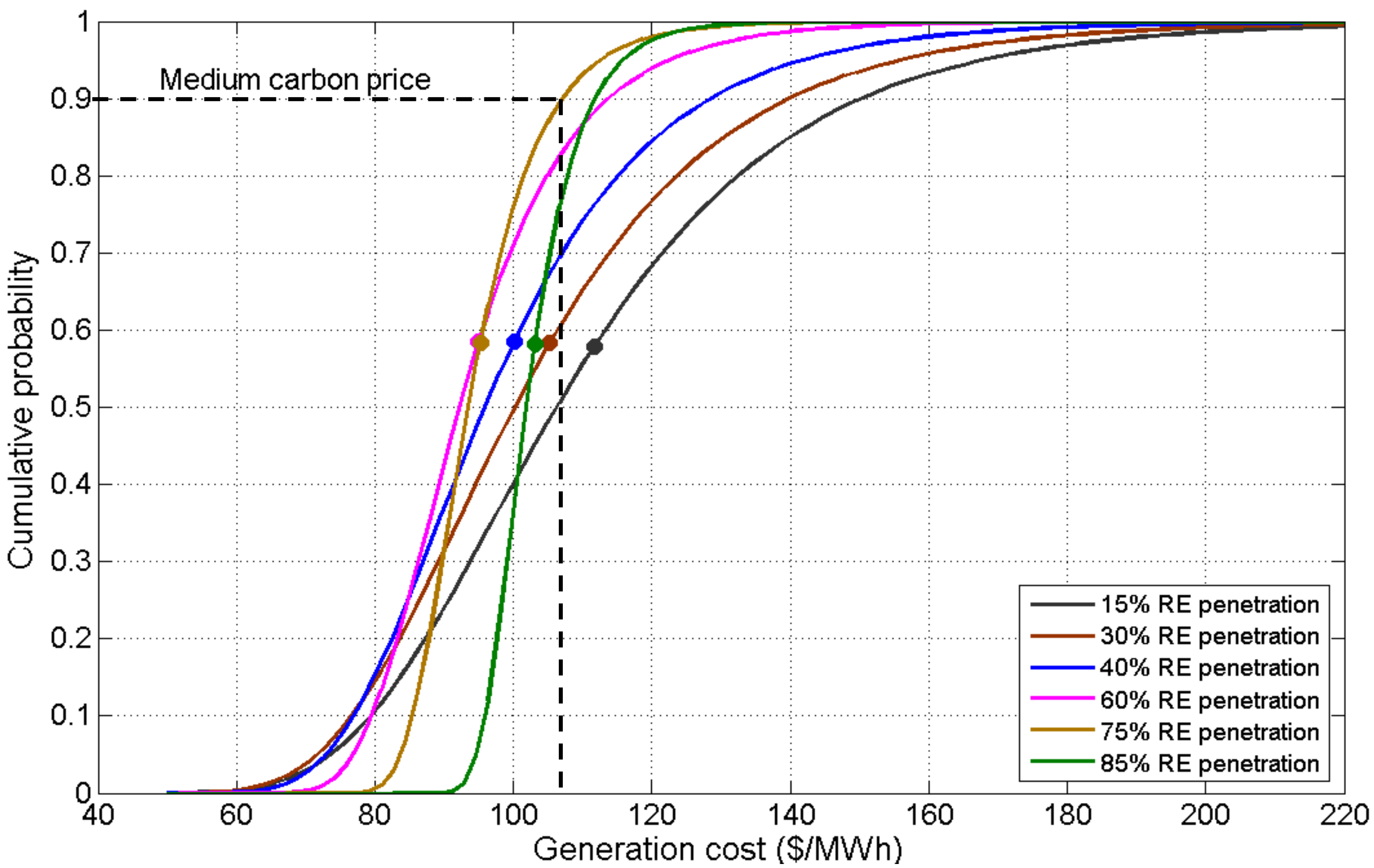
Cost distribution of generation portfolios



Generation cost distribution of the 'Least cost' portfolio for different renewable penetration

- A full spectrum of possible cost outcomes
  - Cost spread (Standard deviation) represents cost risk
  - Less cost spread (i.e. 'cost risk) with greater renewable penetration

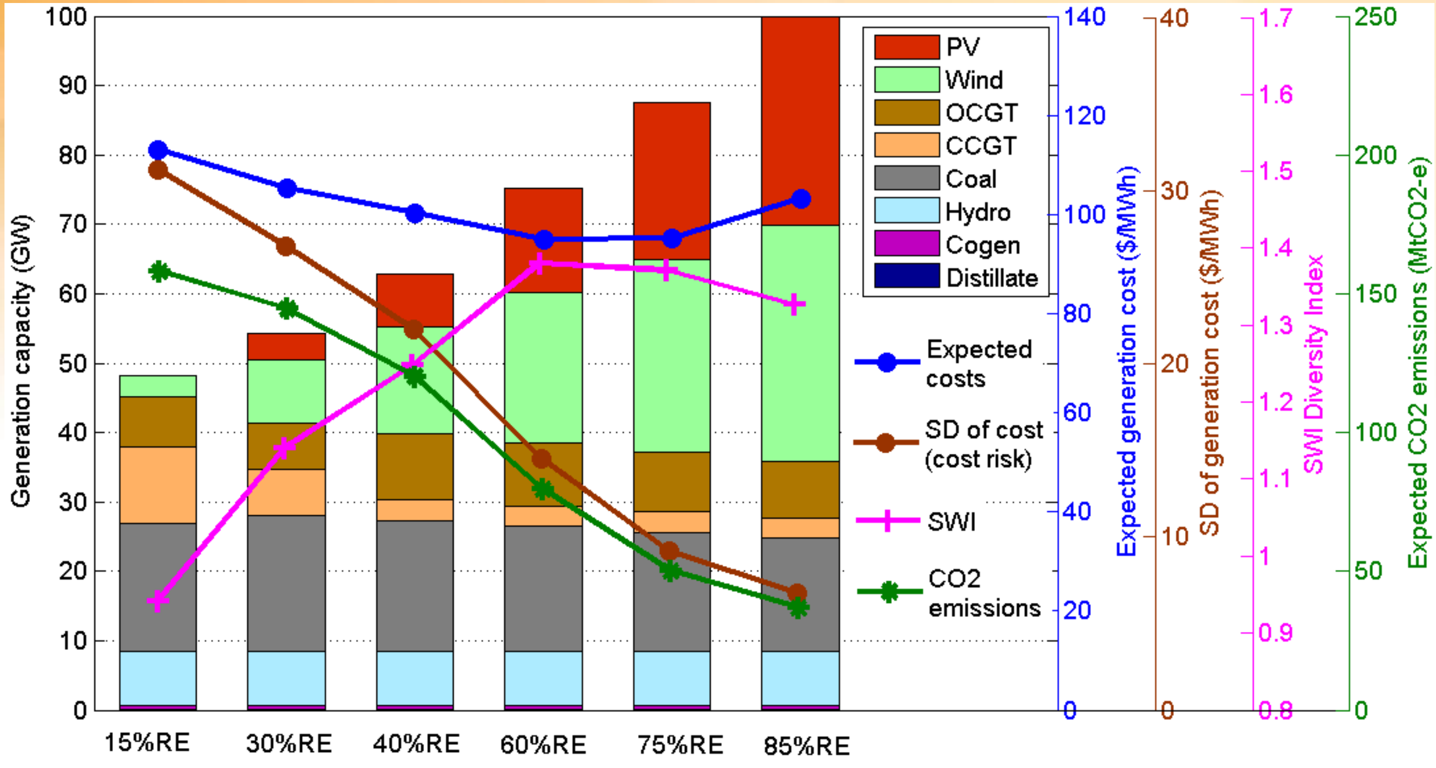
Statistically comparing generation portfolios



Cumulative probability of generation cost

- For the 75% RE portfolio -> 90% chance that costs > $110/MWh
- For the 15% RE portfolio -> 10% chance that costs < $150/MWh

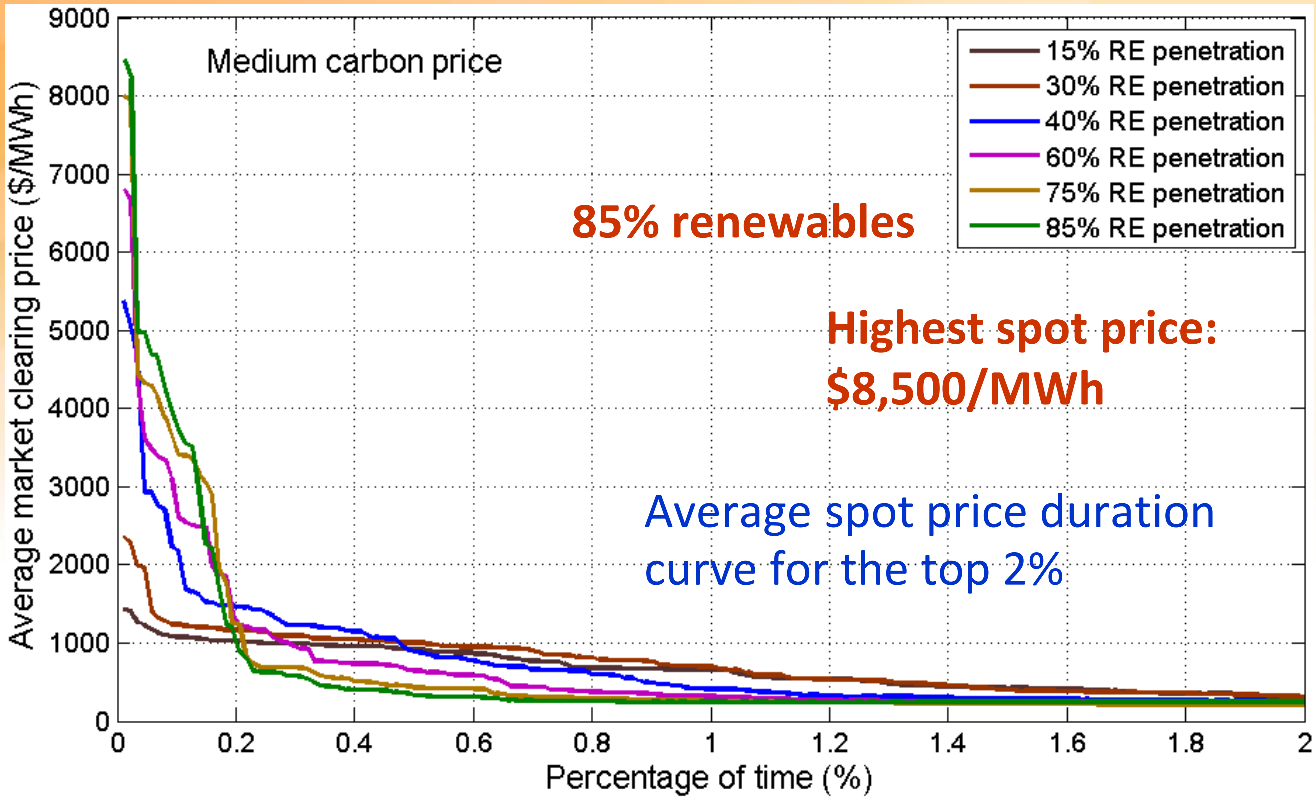
Example – comparing generation portfolios against multiple criteria



'Least cost' portfolios for each RE penetration

- *Technology mix*
- *expected cost*
- *cost risk*
- *CO_2 emissions*
- *Fuel diversity*

Example - Impact of renewables on market prices



RE Penetration	15%	30%	40%	60%	75%	85%
Highest price ($/MWh)	1,400	2,400	5,400	6,800	8,000	8,500
Average price ($/MWh)	135	139	129	114	86	66
No. of high price periods (>$500)	112	114	77	56	36	28

Key aspects of the model

Flexible and transparent

- Can be adjusted to suit particular circumstances of industry stakeholders
- Capable of exploring a wide range of issues which may have implications for generation investment and planning decisions

Formally incorporate uncertainty and risk assessment

- Multiple and interacting key uncertainties. Any probability distributions can also be used to model uncertainties
- Various risk measures beyond SD can be devised

Providing a basis for comparing tradeoffs among possible alternative future generation portfolios

- Taking into account multiple criterion electricity industry objectives (i.e. cost, risk, fuel diversity, greenhouse emissions).
- Facilitate policy and investment decision making

Challenges and limitations

- Availability of hourly demand and renewable generation data.
- Prob. distributions of uncertain parameters can be difficult to determine
- Computation time – Monte Carlo simulation is computationally intensive particularly if there are many uncertain parameters
- Since it uses load duration curve, chronology of electricity industry operation is not considered in the model
  - But the operational analysis can be integrated using PLEXOS (a commercial power market modelling software tool)
- Assuming SRMC bidding - strategic bidding behaviors are not considered
- The modelling tool is currently in a research implementation stage
  - Challenging for general users without MATLAB knowledge
  - Future plant to transfer the modelling algorithms to an open-source and more user-friendly application

Applications of the modelling tool

- Assessing the value of renewables in hedging against future electricity industry uncertainties.
- Examining the impact of EV and solar PV on future generation portfolio investment.
- Assessing “Gas Transition” pathways to low carbon electricity.
- Analysis market pricing and revenue outcomes with high renewables.
- The impact of operational constraints on future generation portfolio investment.
- Assessing long-term security of electricity supply and the role of renewable energy.
- Modelling future electricity generation portfolio investment under a carbon price in China’s electricity industry.

Further reading

- Vithayasrichareon, P., and MacGill, I.F., 2012. A Monte Carlo based decision-support tool for assessing generation portfolios in future carbon constrained electricity industries. *Energy Policy 41, 374-392*.
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- Vithayasrichareon, P., Riesz, J., and MacGill, I.F., 2015. Using renewables to hedge against future electricity industry uncertainties—An Australian case study. *Energy Policy 76*.
- Vithayasrichareon, P., Mills, G., and MacGill, I., 2015. Impact of Electric Vehicles and Solar PV on Future Generation Portfolio Investment. *IEEE Transactions for Sustainable Energy.*
- Riesz, J., Vithayasrichareon, P., and MacGill, I.F., 2015 Assessing "Gas Transition" pathways to low carbon electricity. *Applied Energy*

Sample MATLAB codes are available DOI: 10.13140/RG.2.1.2318.7367

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