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Electricity Generation Portfolio Evaluation for Highly Uncertain and Carbon Constrained Electricity Industries

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Presentation Outline

- **Background**
  - ➢ Challenges in electricity industry investment
  - ➢ Conventional approaches in electricity investment
- **Generation investment under uncertainty**
- **Generation portfolio assessment model**
- **Case study**
  - – Descriptions
  - – Results
- **Conclusions**

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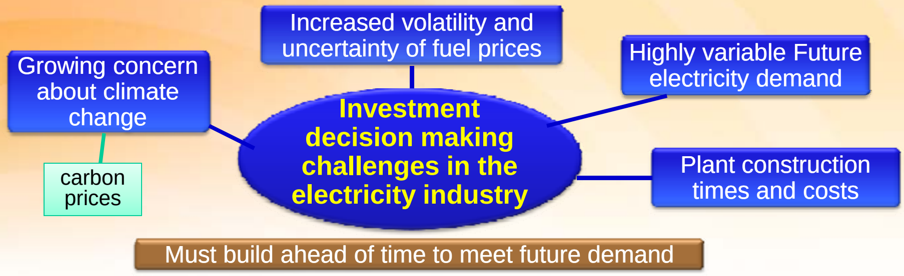
Electricity investment challenges



- Uncertainties have substantial impact on generation investment decision making
  - *Conventional tools in planning & investment often ignore uncertainties*
- Value to formally incorporate risk assessment into decision support tools for generation investment
  - *Challenging as key drivers are uncertain and correlated – fuel prices carbon price, future electricity demand*

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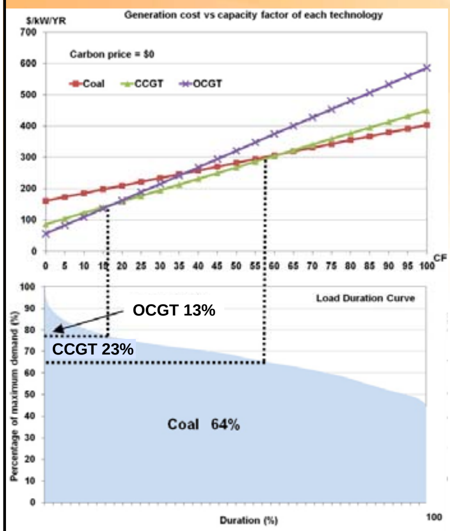
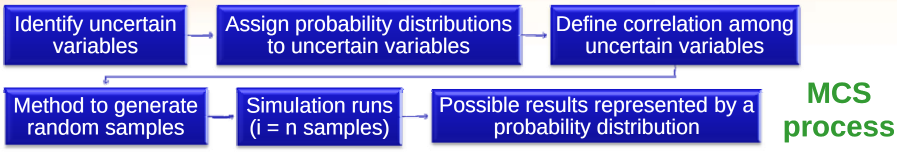
Conventional tools in electricity investment



- Often focus on finding the least cost future generation portfolios to meet future demand
  - *Discounted cash flow, levelized Cost*
  - *deterministic assumptions i.e. fuel prices, demand, carbon prices, capacity factor of generating plants*
  - *For example: Conventional optimal generation mix method*
- Expanded assessments might include Scenario and Sensitivity Analysis
- Under 'cost recovery regime' – may insulate those that make decisions

Investment tools incorporating uncertainty

- Several methods to implicitly address risks and uncertainty.
- Stochastic approach based on Monte Carlo Simulation (MCS) technique is a comprehensive and flexible method.
  - *Can analyze problems with many uncertain parameters*
  - *Outputs represented by probability distribution*



- Drawbacks of MCS – Probability distribution of uncertain variables can be difficult to estimate, computation time (accuracy VS computation time)

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Monte Carlo optimization model

- Extends deterministic method by incorporating uncertainty into key cost assumptions using Monte Carlo simulation technique.
- Combines stochastic analysis with generation portfolio-based analysis
- Calculate the expected generation cost of various generation portfolios ($/MWh).
  - *Assess cost, 'cost uncertainty' (risk) and CO_2 emissions of different possible generation portfolios.*
  - *Contribution of each technology to the cost and risk of the entire generation portfolio*
  - *Generation cost outputs from MCS represent a range of possible results - Mean and SD are used to measure cost-risk profile.*

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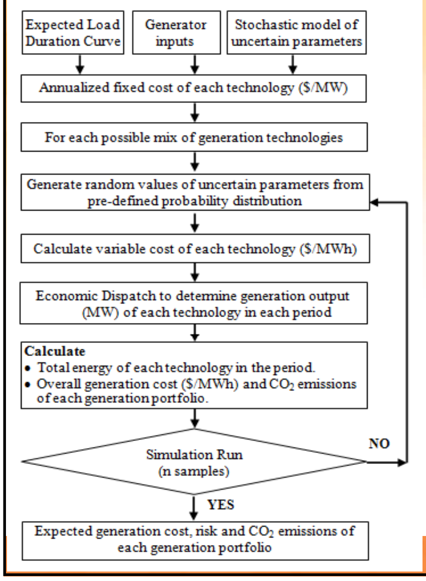
Monte Carlo optimization model



- Total generation cost ($/MWh) = Fixed Cost + Variable Cost
- FC = annualised fixed cost ($/MW/yr)
  - *incur regardless of energy produced*
- VC = O&M cost + Fuel cost + Carbon cost ($/MWh)
  - *depends on energy produced*
- Amount of energy generated by each technology is determined from economic dispatch in each dispatch period

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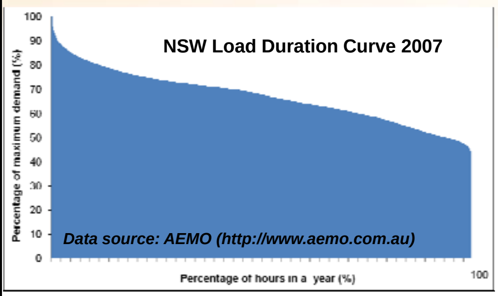
Model inputs

Attributes**	Technology		
	Coal	CCGT	OCGT
Plant life (Years)	40	25	25
Capital cost ($/MW)	1,400,000	650,000	450,000
Fixed O&M ($/MW/yr)	43,000	25,000	14,000
Efficiency (%)	42	58	43
Variable O&M ($/MWh)	3.3	1.5	6.5
EF(tCO_2/MWh)	0.8	0.35	0.47

***** Sources: IEA, NEA/IEA (2005)***



- Generator inputs
  - *Technological parameters of each technology*
- Expected Load Profile
  - *Yearly Load Duration Curve*
- Stochastic model of uncertain parameters
  - *Fuel prices, Carbon prices*
  - *Correlation between fuel and carbon prices*

	Carbon price ($/tCO2)	Coal price ($/GJ)**	Gas Price ($/GJ)**
Mean	20	2.85	6.45
SD	10	0.285	1.935

***** Sources: IEA, "Coal Information 2008"***
IEA, "Gas Information 2008"

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Case study

- Consider various generation portfolios of 3 technologies: Coal, CCGT and OCGT - *Share of each technology ranges from 0-100% of total capacity in 20% increments: 21 generation portfolios*
- For each portfolio – the calculation of cost is repeated for 5,000 simulated single years of uncertain and correlated fuel and carbon prices.
- Results from the model consist of
  - *Expected generation cost ($/MWh)*
  - *SD of generation cost, which represents the 'cost uncertainty' (risk).*
  - *Expected CO_2 emissions of each generation portfolio (tCO_2/yr)*

No.	%Share of technology		
	coal	CCGT	OCGT
1	0	0	100
2	0	20	80
3	0	40	60
4	0	60	40
5	0	80	20
6	0	100	0
7	20	0	80
8	20	20	60
9	20	40	40
10	20	60	20
11	20	80	0

No.	%Share of technology		
	coal	CCGT	OCGT
12	0	0	100
13	0	20	80
14	0	40	60
15	0	60	40
16	0	80	20
17	0	100	0
18	20	0	80
19	20	20	60
20	20	40	40
21	20	60	20

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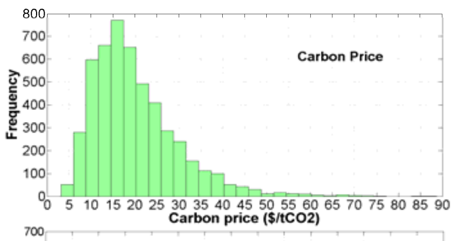
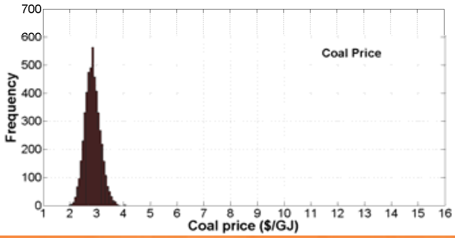
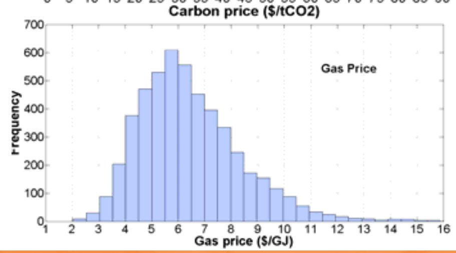
Modeling uncertain parameters

- Lognormal distribution to represent fuel and carbon price uncertainty – *allows for greater downside risk from high prices*
- Generate correlated 5,000 sets of correlated random coal, gas and carbon prices using Multivariate lognormal simulation







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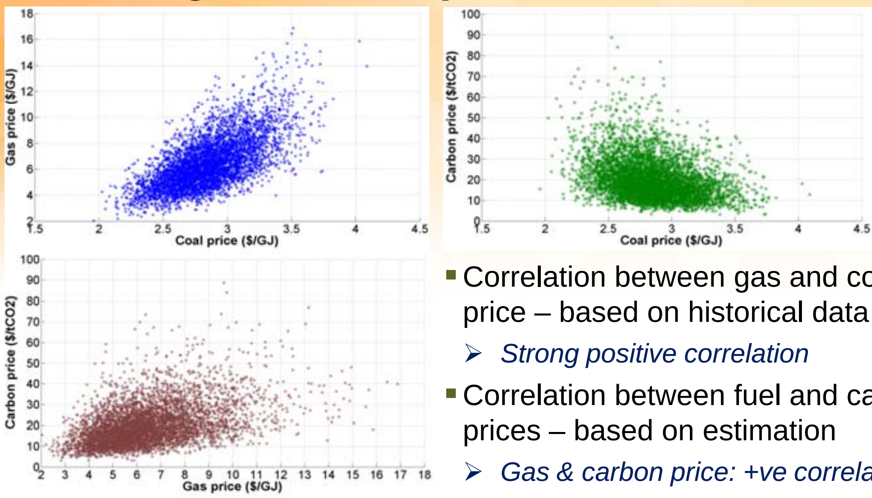
Modeling uncertain parameters



- Correlation between gas and coal price – based on historical data
  - *Strong positive correlation*
- Correlation between fuel and carbon prices – based on estimation
  - *Gas & carbon price: +ve correlation*
  - *Coal & carbon price: -ve correlation*

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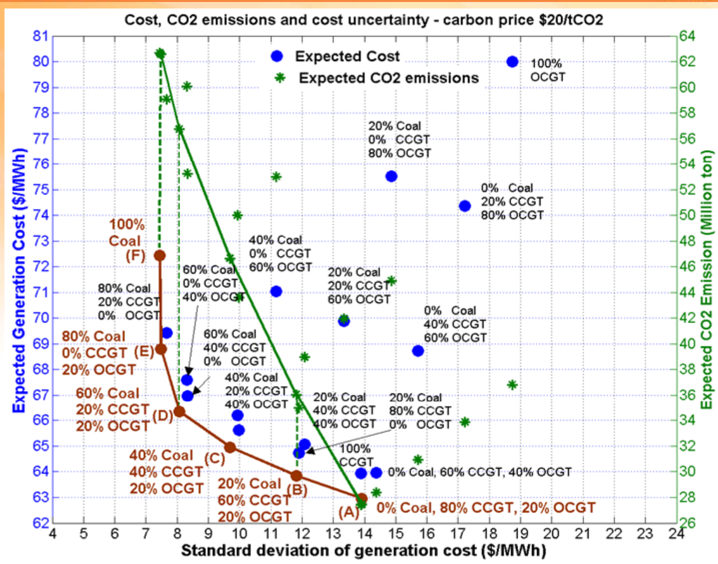

Efficient Frontier (EF) – the generation cost cannot be reduced without increasing 'cost uncertainty'

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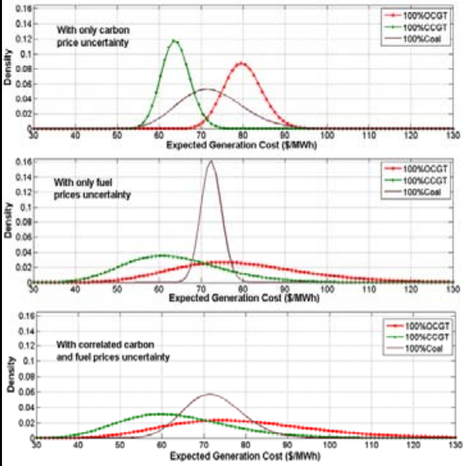
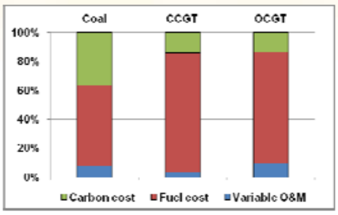
Impact of different sources of uncertainties



- Impact of gas price uncertainty on CCGT and OCGT is more influential than the impact of carbon price uncertainty on coal
  - *Although the volatility of carbon price is greater than fuel price.*



- CCGT & OCGT face a much higher fuel price uncertainty since fuel cost is the largest cost component

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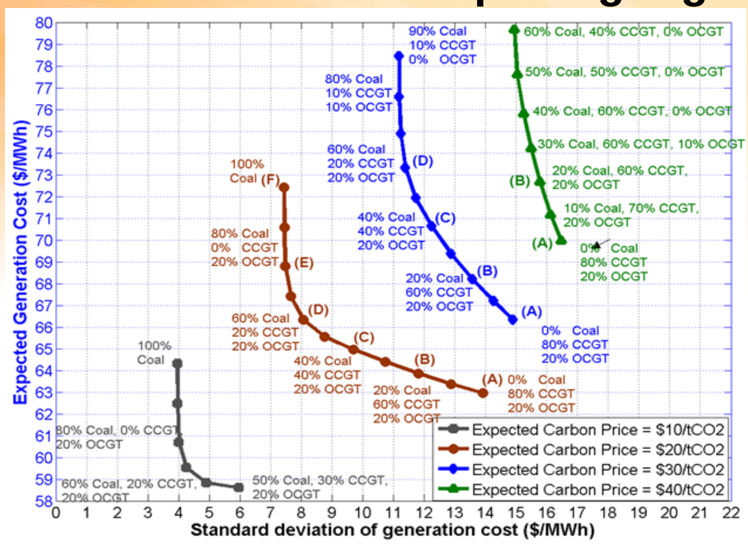
Impact of different carbon pricing regimes



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Conclusions

- Simulation results demonstrate
  - *Trade-off between cost, risk and CO_2 emissions among different portfolios*
  - *Contribution of each technology to cost and risk of the entire portfolio*
  - *The impact of different sources of uncertainties*
  - *The impact of different carbon prices*
- The model has potential to support decision making in generation investment
  - *Accommodate various uncertainties, generation technologies, load profile.*
  - *Analyse various generation portfolios - highlight and identify cost-risk tradeoffs between different generation portfolios*
  - *Allowing appropriate generation portfolios to be identified in terms of cost, risk and CO_2 emissions.*

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Thank you,

and

Questions?

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Annualized fixed cost and CRF

Annualized fixed cost

= Overnight capital cost ($/MW) x CRF

where

CRF is the capital recovery factor which determines the equal amount of regular payment in a present amount of money

$$CRF = \frac{i(1+i)^m}{(1+i)^m - 1}$$

i – discount rate (assume 8%)

m – plant life

Multivariate lognormal simulation

$$mu = log\left(\frac{\mu^2}{\sqrt{\sigma^2 + \mu^2}}\right) \qquad sigma = \sqrt{log\left(\frac{\sigma^2}{\mu^2} + 1\right)}$$

	Carbon price ($/tCO2)	Coal price ($/GJ)	Gas Price ($/GJ)
Mean (μ)	20	2.85	6.45
SD (σ)	10	0.285	1.935

Correlation Coefficient	Coal price	Gas price	Carbon price
Coal price	1	0.65	-0.32
Gas price	0.65	1	0.45
Carbon price	-0.32	0.45	1

Joint probability distribution

P(coal ∩ gas) = P(gas |coal).P(coal)

P(gas | coal) = P(coal ∩ gas) / P(coal)

- Generate a set of correlated random parameters using multivariate lognormal simulation – statistical toolbox in MATLAB (require correlation matrix, mu, sigma)

Random parameters from simulation

- Correlated random coal, gas and carbon prices from 5,000 simulations have been verified to possess the same statistical features as the input structure i.e. correlation, mean and variances

Correlation	Coal price	Gas price	Carbon price
Coal price	1	0.655	-0.316
Gas price	0.657	1	0.45
Carbon price	-0.316	0.45	1

	Carbon price ($/tCO2)	Coal price ($/GJ)**	Gas Price ($/GJ)**
Mean	20.04	2.85	6.455
SD	9.8	0.282	1.935

Probability density function of costs