



# Monte-Carlo Optimization Framework for Assessing Electricity Generation Portfolios

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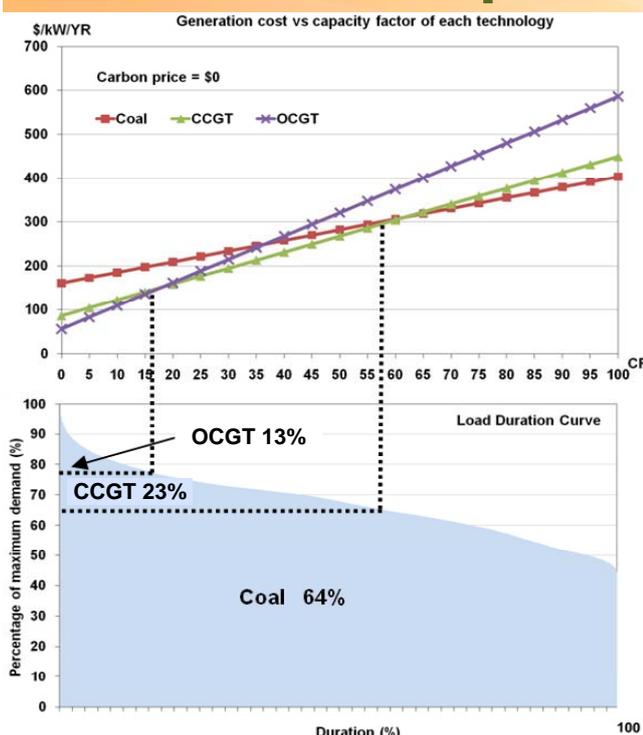
## Presentation Outline

- **Context**
- **Introduction**
  - Traditional Optimal Generation Mix
  - Stochastic approaches to incorporate uncertainty
- **Methodology**
  - Model Framework
- **Case Study**
  - Description
  - Results
- **Conclusion**

## Context

- Electricity industry faces growing uncertainties
  - *Fuel prices, climate change policy and energy demand.*
- Uncertainties have substantial impact on generation investment decision making
  - *Capital intensive, long lead times, irreversible.*
- Minimise exposure to economic risks ('cost uncertainty') is as important as minimising cost
  - *Price stability has economic value for end-users*
  - *Investors may put more weight on risk than on expected costs*
- Value to incorporate risk assessment into decision support tools for generation investment
  - *Challenging as key drivers are uncertain and correlated*

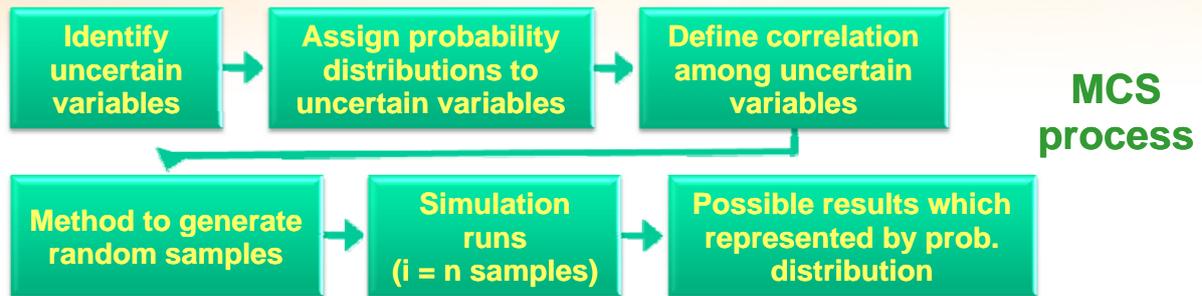
## Traditional Optimal Generation Mix



- Method to solve for least-cost generation mix given deterministic assumptions.
- Although simple and useful, it does not incorporate a wide range of relevant issues:
  - *'Sunk' existing assets Vs new plants, reserve requirement*
- **This method ignores uncertainties such as fuel prices, energy demand and climate change measures.**
  - *Main focus of this study*

## Approaches to incorporate 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 analyse problems with many uncertain parameters*
  - *Outputs represented by probability distribution*



- Drawbacks of MCS – Prob. of variables can be difficult to estimate, computation time (accuracy VS computation time)

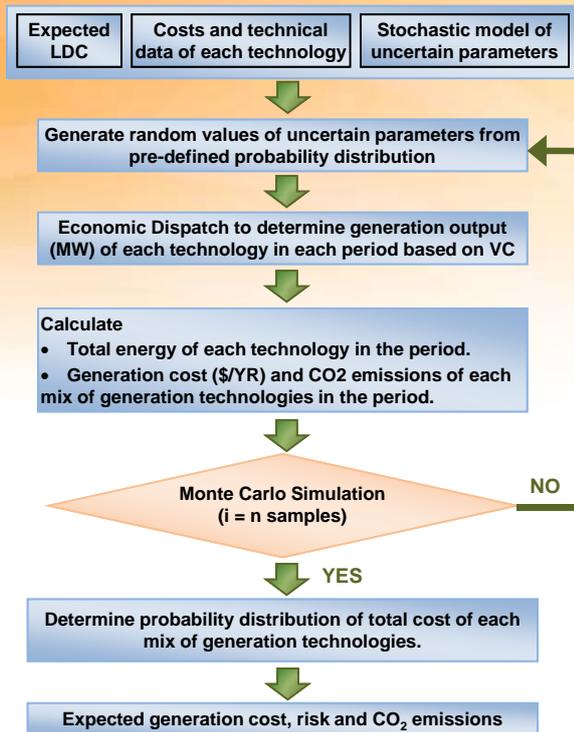
## Model Framework

- Extends deterministic method by incorporating uncertainty into key cost assumptions using MCS technique.
  - *Assess cost and risk of different possible generation portfolios.*
- Calculate the expected generation cost of various generation portfolios in a year.
- Consider generation portfolios instead of single technology or deterministically solving for a least-cost generation mix
  - *Contribution of each technology to the cost and risk of the entire generation portfolio*
- Extension and contribution to current literatures
  - *Standard DCF & probabilistic analysis<sup>1</sup>, MVP approach<sup>2</sup>*

<sup>1</sup> P. Spinney and G. Watkins, 1996., D. Feretic and Z. Tomsic, 2005., F. Roques, W. Nuttall, and D. Newbery, 2006.

<sup>2</sup> S. Awerbuch, 2006., J. Jansen, L. Beurskens, and X. Tilburg, 2006. S. Awerbuch and M. Yang, 2008.

## Model Framework



- Total generation cost (\$/yr)  
= 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 tech. is determined using economic dispatch based on VC.

## Model Framework

- Generation cost outputs from MCS represent a range of possible generation costs which can be represented by a probability distribution
  - *Assume normal distribution - Mean and SD are used to measure cost-risk profile. SD is used to measure risk ('cost uncertainty') which is the spread of possible outcomes.*

## Assumptions

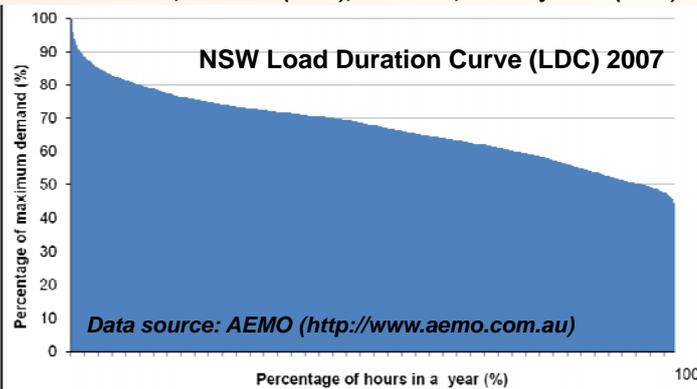
- Adopts a social welfare maximisation perspective
  - *Focus on overall industry electricity generation cost*
- Installed capacity is always sufficient to meet demand.
- Only considers economic risk arising from fuel and carbon prices uncertainty – ignore technical or operational risks.

## Case Study

Attributes**	Technology		
	Coal	CCGT	OCGT
Capital cost (\$/MW/yr)*	160,500	86,000	56,200
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
Emission factor (tCO <sub>2</sub> /MWh)	0.8	0.35	0.47

\*Calculated from overnight cost using CRF with 8% discount rate

\*\* Sources: IEA, NEA/IEA (2005), PBPower, Doherty et al. (2006)



- This model is applied to a case study
- Generation mix of 3 tech: Coal, CCGT & OCGT
- Scenario of fuel and carbon prices uncertainty.
- Consider various generation mix scenarios
  - Share of each tech ranges from 0-100% of total capacity in 20% increments
  - hence 21 possible generation portfolios

## Case Study

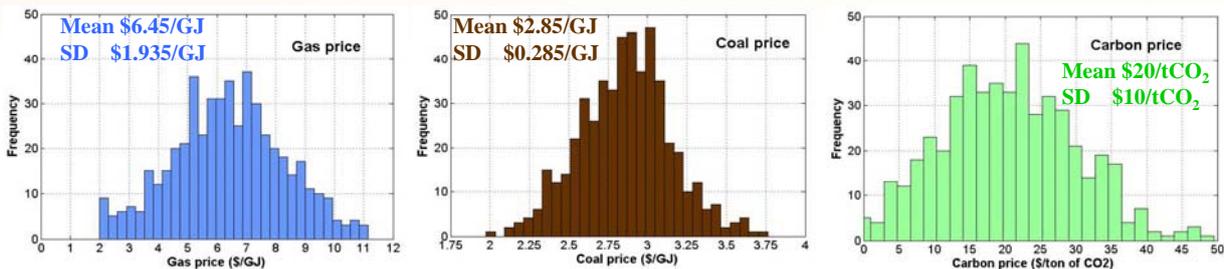
- Fuel and carbon prices is assumed to be normally distributed
- Mean and SD of fuel prices based on historical data<sup>1,2</sup>
  - Gas price: Mean = \$6.45/GJ, SD = 30% of mean (\$1.935/GJ)
  - Coal price: Mean = \$2.85/GJ, SD = 10% of mean (\$0.285/GJ)
- Mean and SD of carbon price based on the assumption
  - Mean = \$20/tCO<sub>2</sub>, SD = 50% of mean (\$10/tCO<sub>2</sub>)
  - Assume high SD to allow for the possibility of significant price variation -- reflects current climate change policy uncertainties
- Assume no correlation among fuel and carbon prices
  - Straightforward to incorporate with this technique
  - Currently under investigation

<sup>1</sup>IEA, "Coal Information 2008" OECD/IEA, Paris, 2008

<sup>2</sup>IEA, "Gas Information 2008" OECD/IEA, Paris, 2008

# Case study results

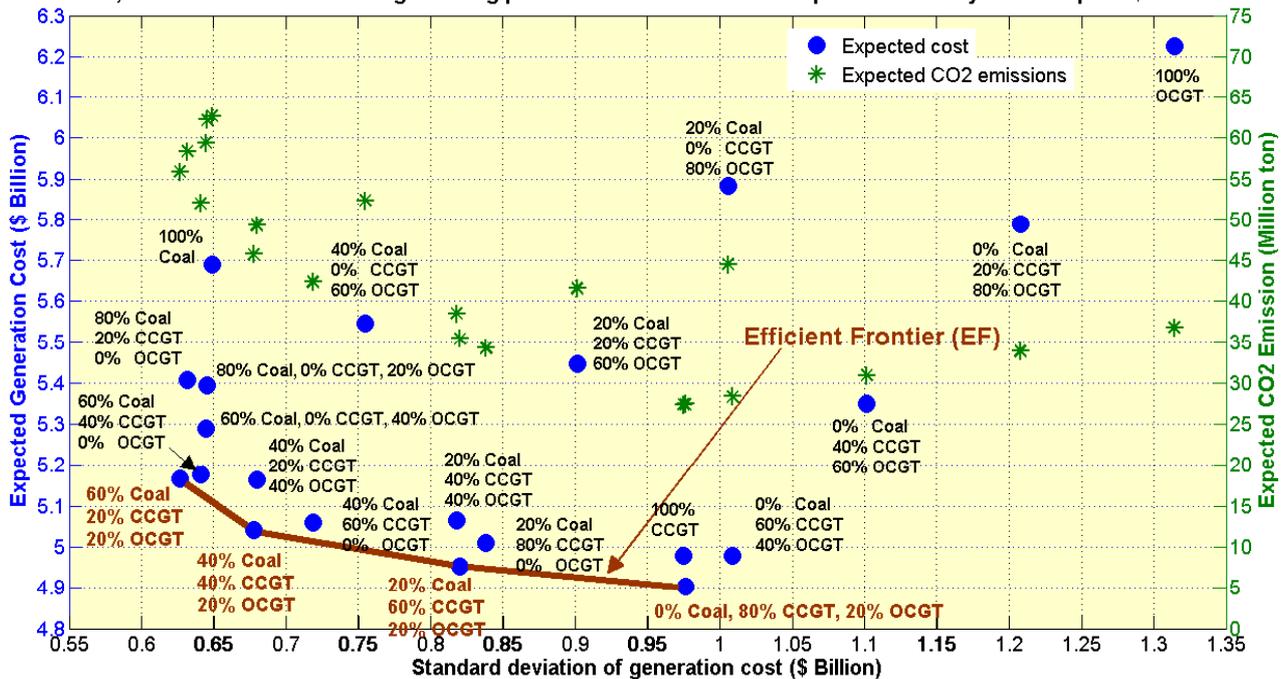
- Results from the model consist of
  - *Expected generation cost (\$/yr)*
  - *SD of generation cost, which represents the volatility or risk.*
  - *Expected CO<sub>2</sub> emissions of each generation portfolio (tCO<sub>2</sub>/yr)*
- For each generation mix – the calculation of cost is repeated for 500 simulated years of uncertain fuel & carbon prices



Distributions of 500 samples of gas, coal and carbon prices for given Mean and SD

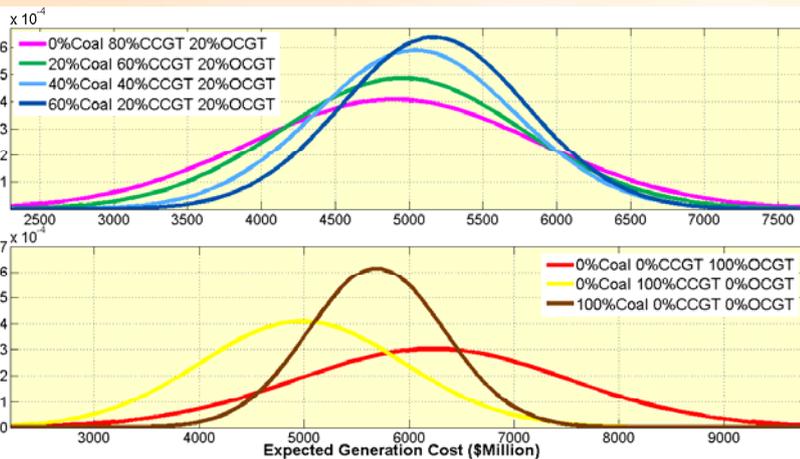
\* Note the constrained normal distribution – minimum threshold for fuel and carbon price

Cost, CO<sub>2</sub> emissions and risk of generating portfolios with fuel and carbon price uncertainty - Carbon price \$20/tCO<sub>2</sub>



*Efficient Frontier (EF) – the generation cost cannot be reduced without increasing ‘cost uncertainty’ (risk).*

- Portfolio of 0%Coal, 80%CCGT, 20%OCGT has the lowest expected cost, but exhibits a relatively high cost uncertainty.
- If increase the share of coal to 20%, replacing the share of CCGT - the portfolio is now 20%Coal, 60%CCGT, 20%OCGT (on EF)
  - *Cost uncertainty is reduced by 15% while gen. cost increases by 1%.*
  - *CO2 emissions also increases by 30%*



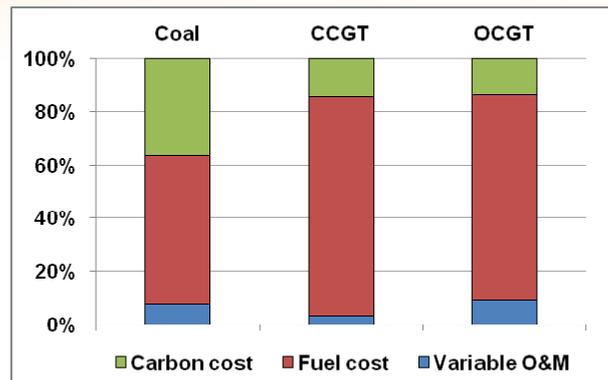
- Comparisons among portfolios can be made by analysing tradeoffs between the cost, risk and CO2 emissions among generation portfolios

## Case study results (Cont')

- Simulation results highlight some significant aspects
- Trade-off between cost and risk among different portfolios
- Contribution of each technology to cost and risk of the entire portfolio
  - *Adding a less (or more) costly technology does not necessarily reduce (or increase) the expected portfolio cost.*
  - *Since the load is not uniform throughout the year - Trade-off between fixed and variable costs enables each technology to play a valuable role in generation portfolio in meeting demand in different periods.*

## Case study results (Cont')

- Impact of gas price uncertainty on CCGT and OCGT is more influential than the impact of carbon price uncertainty
  - Although the volatility of carbon price is greater than that of fuel price, CCGT & OCGT face a much higher fuel price uncertainty since fuel cost is by far the largest cost component (given assumed expected carbon price)



## Conclusions

- The model is powerful yet flexible
  - Accommodate various uncertainties, varied type of generation technology, load profile, any form of probability distribution for stochastic parameters.
  - Analyse various generation portfolios - highlight and identify cost-risk tradeoffs between different generation portfolios
- Incorporation of load profile
  - Generation output is determined in a more practical way
  - Capture economic merits of each technology
  - Tradeoffs between fixed and variable cost of each technology
- The model has a significant potential to support decision making in generation investment under various uncertainties
- The results are sensitive to inputs and price assumptions.



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