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Modelling Electricity Generation Investment and Carbon Price

China – Australia Carbon Market Design Expert Workshop
Shanghai, China, 11 September 2013

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Outline

- Role of the electricity industry
- Challenges in the electricity industry
- Generation investment decision making
- Uncertainties and their implications
- Existing generation investment frameworks
- Probabilistic generation portfolio modelling tool
- Some examples

Role of the electricity industry

- The electricity industry plays a vital role in socio-economic development
  - *Social – Affordable electricity access is key to poverty eradication and improved quality of life (WEC, 2007)*
  - *Economic – energy availability is key driver in the economic growth.*

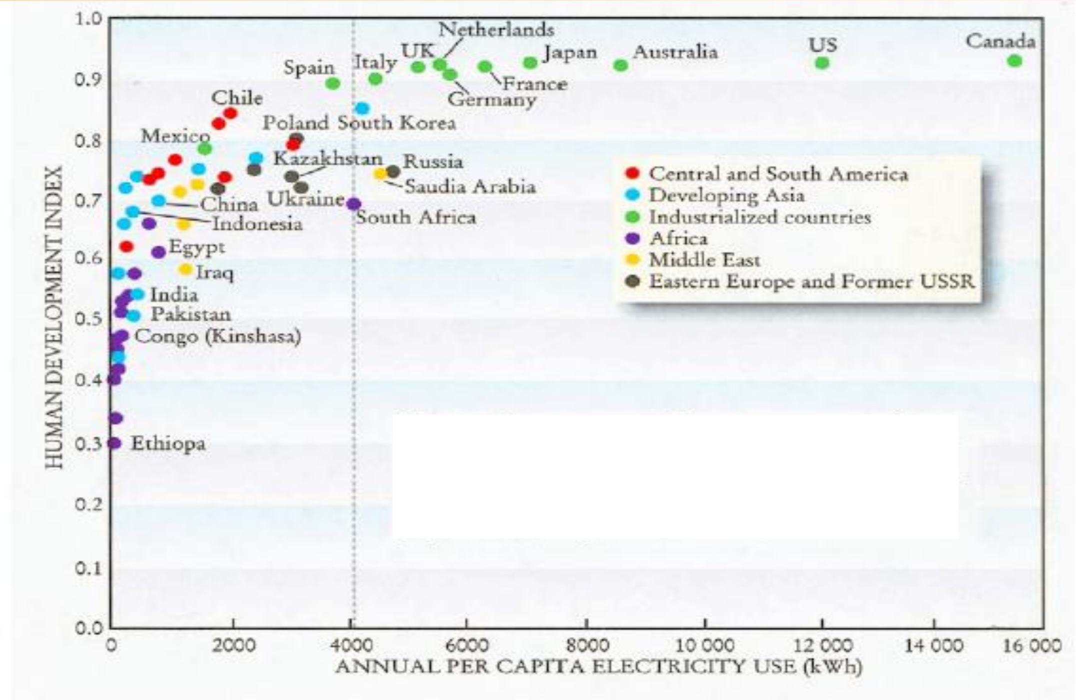
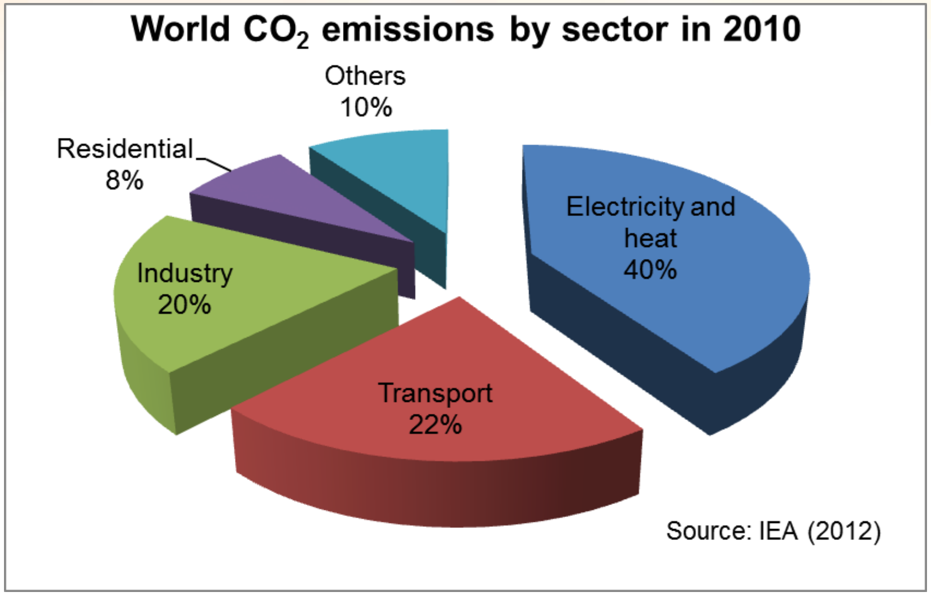


Figure 1.2. Human development index vs. per capita electricity use for selected countries. Taken from S. Benka, *Physics Today* (April 2002), pg 39, and adapted from A. Pasternak, Lawrence Livermore National Laboratory rep. no. UCRL-ID-140773.

- Environmentally?
  - *the World's present energy systems are primary drivers of environmental challenges – Climate Change.*

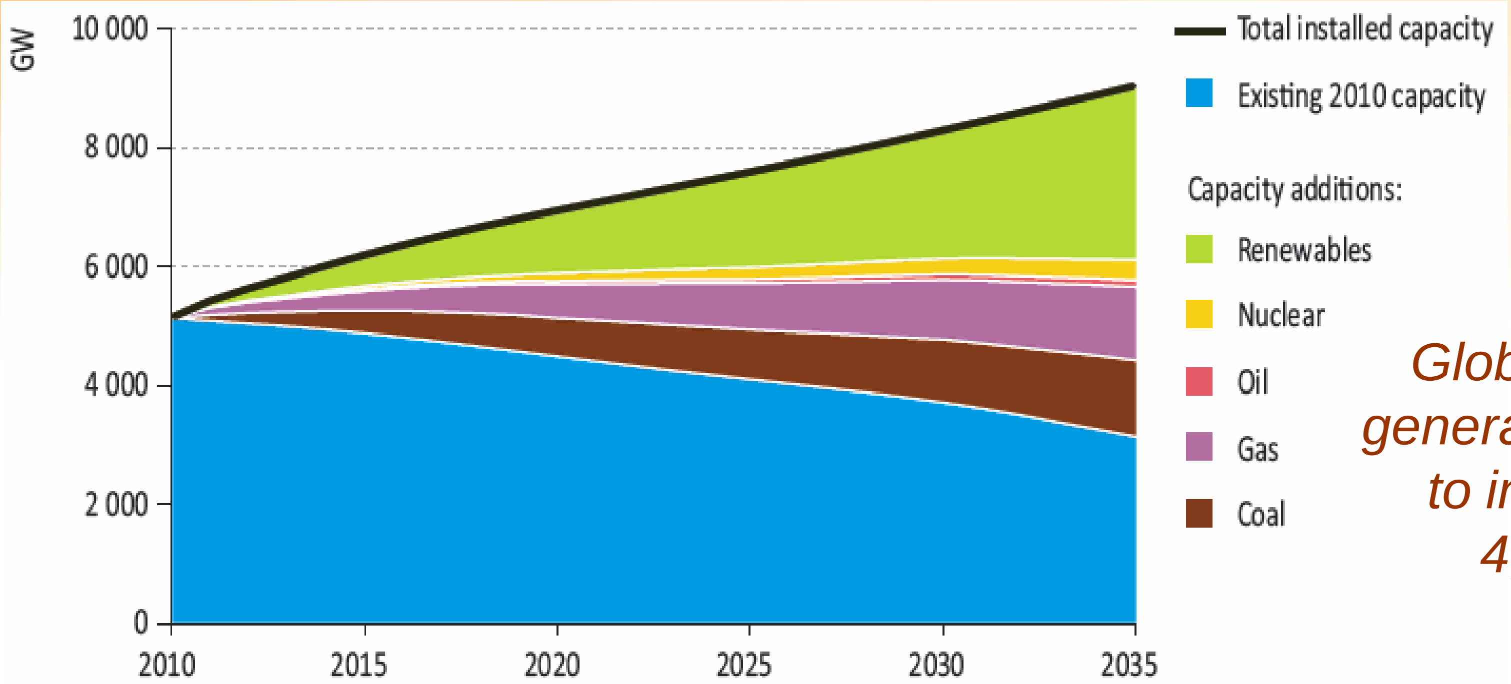
Challenges in the electricity industry

- Increasing challenges for electricity industries around the world
  - *Rapid and highly uncertain demand growth*
  - *Energy security concerns – Aging infrastructure, high dependence on fossil-fuels.*
  - *Environmental sustainability – the electricity sector is the largest single contributor to global GHG emissions (IEA, 2012).*



Challenges in the electricity industry

- $17 trillion of global investment is required over the next 20 years to expand infrastructure and meet demand growth (IEA 2012)
  - *60% in generation capacity, 40% in network.*



Global installed generation capacity and additions by technology type (IEA, 2011)

Global installed generation capacity to increase by 4,000GW

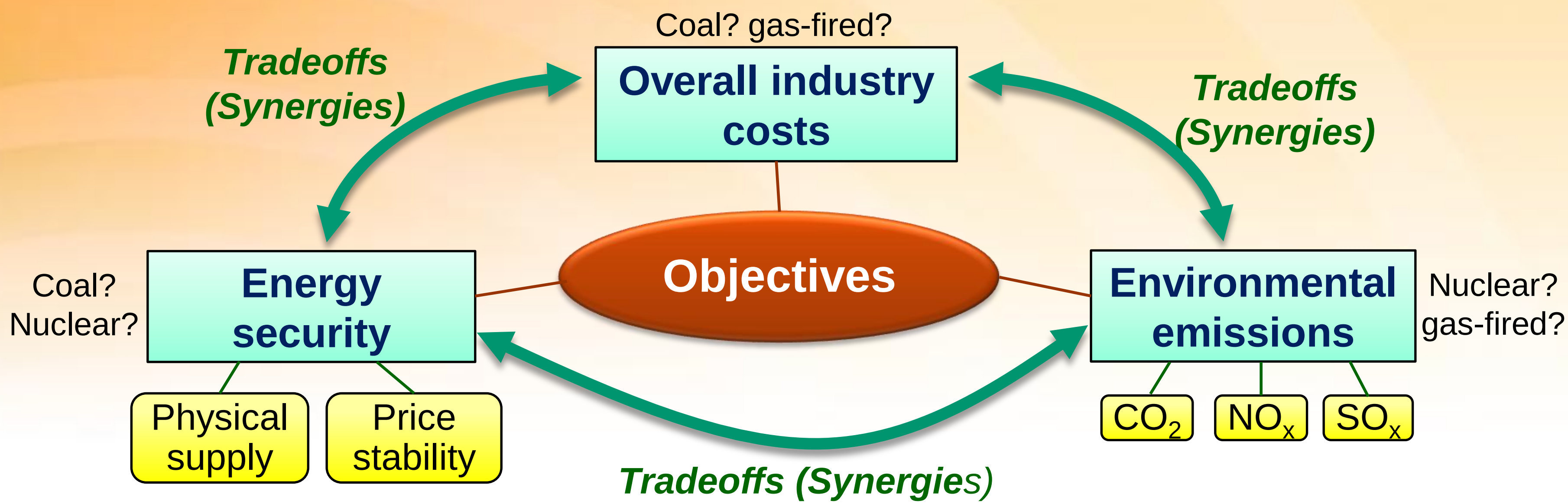
Generation investment decision-making

- One of the most critical and challenging decisions
  - Complex nature of generation investment*: Capital intensive, long-lived assets, significant lead times, irreversible.*
  - *Must commit large investments ahead of time.*
- Particularly challenging for countries with *rapid social & economic development – leads to high electricity demand growth*
  - *Require investments in supply infrastructure over short timeframes.*
- Different generation investment options with different characteristics (economic, operating, emissions)

Technology	Capital cost	Operating cost	Emissions
Coal-fired	High	Low	High
CCGT	Moderate	Moderate	Moderate
OCGT	Low	High	Moderate
Nuclear	Very high	Low	Low
Renewables	High	Very low	None

Generation investment decision-making

- ***Multiple objectives (and criteria)*** nature.



Potential conflicts between these objectives in many countries

- **Coal plants** - *cheap* to run but *high emissions*.
- **Gas-fired plants** - *energy security concerns* but *low emissions*.
- **Nuclear** - *expensive* to build but *zero operating emissions*.

Generation investment decision-making

Uncertainty is the only Certainty….

Key cost factors are uncertain

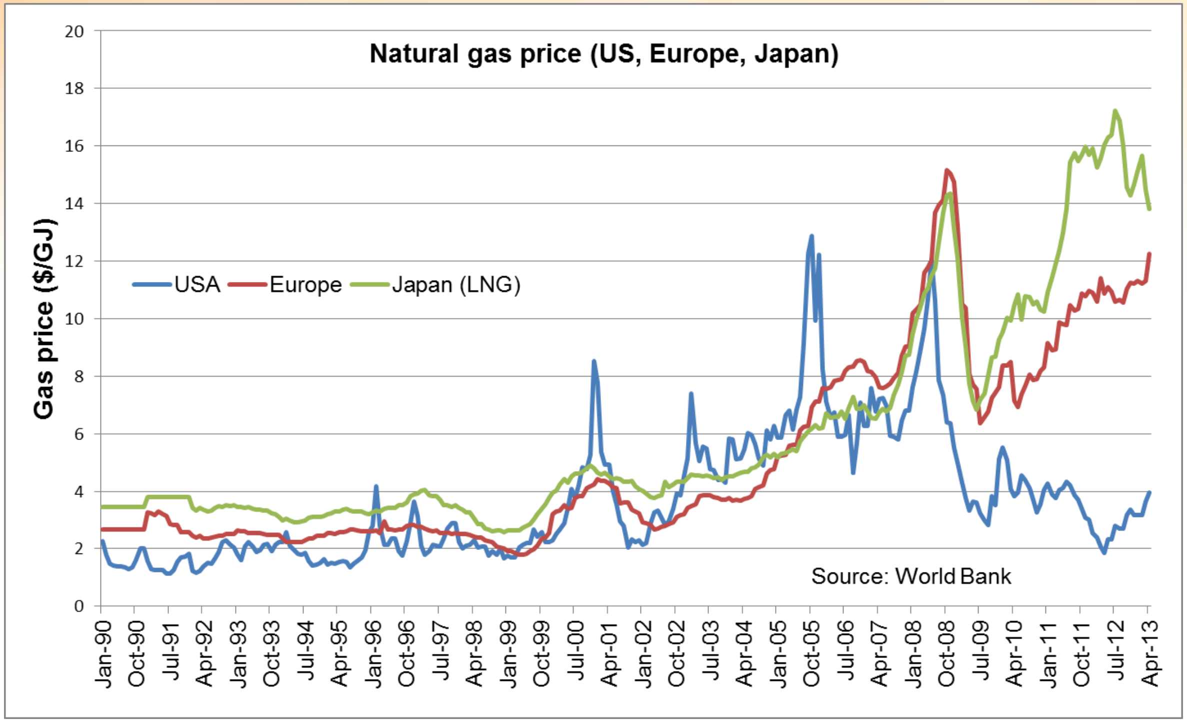
- *Future fossil fuel prices*
- *Demand growth*
- *Climate change policy (i.e. carbon price)*
- *Other cost factors such as plant capital costs.*

Increase complexity of generation investment decision making.

Uncertainties need to be taken into account in generation investment decision making.

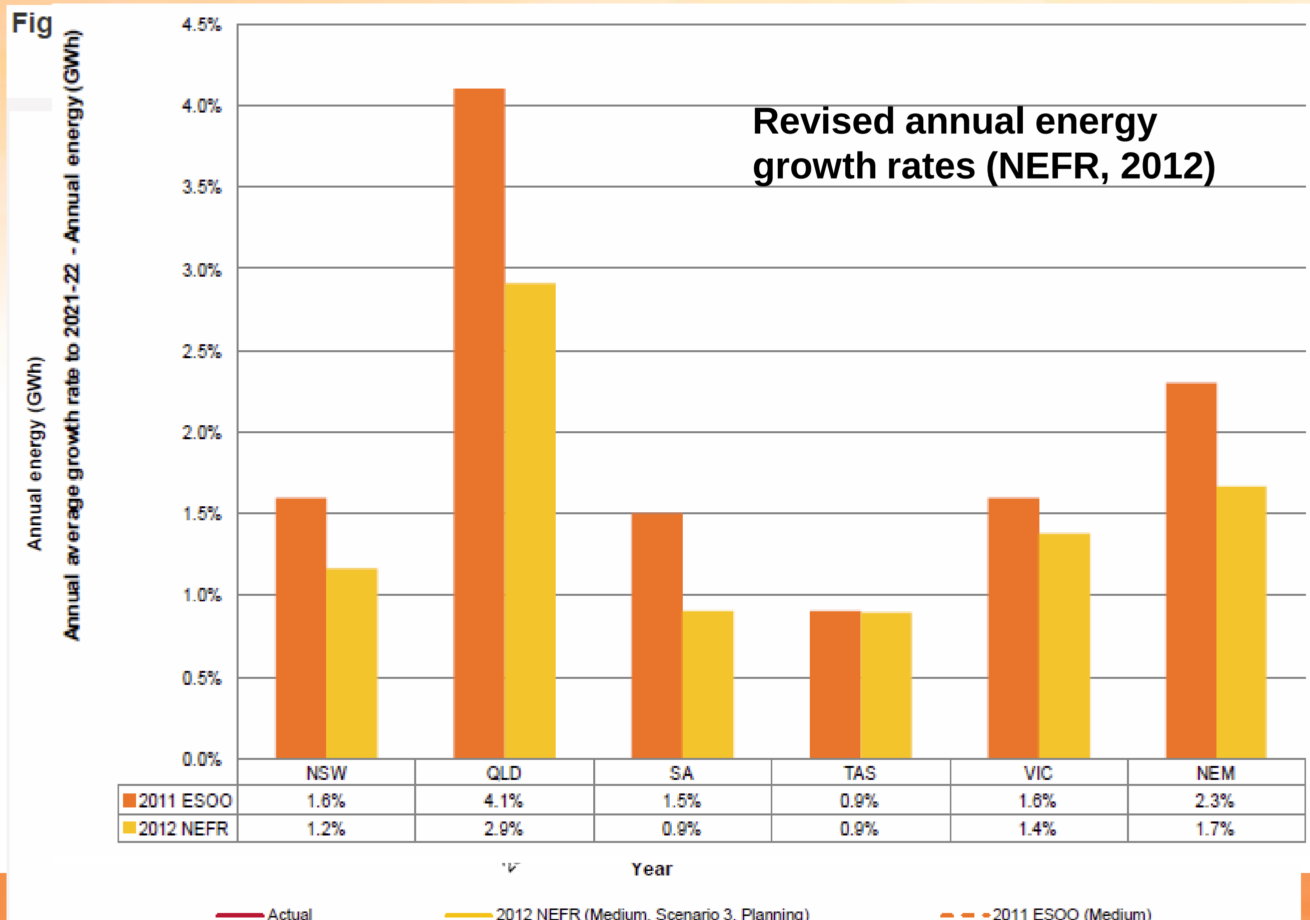
Uncertainty in key cost factors

- Significant fluctuation in fossil-fuel prices over the last decade
  - *Exposed to fuel price risks and availability.*



Uncertainty in key cost factors

- Demand projection can change markedly over planning horizon
  - ➢ *Changes in economic outlook, significant penetration of distributed RE*



	NSW	QLD	SA	TAS	VIC	NEM
2011 ESOO	1.6%	4.1%	1.5%	0.9%	1.6%	2.3%
2012 NEFR	1.2%	2.9%	0.9%	0.9%	1.4%	1.7%

Uncertainty in key cost factors

- Climate change policies – putting a ‘price’ on carbon emissions through either *‘market based’* mechanisms or *‘carbon tax’.*

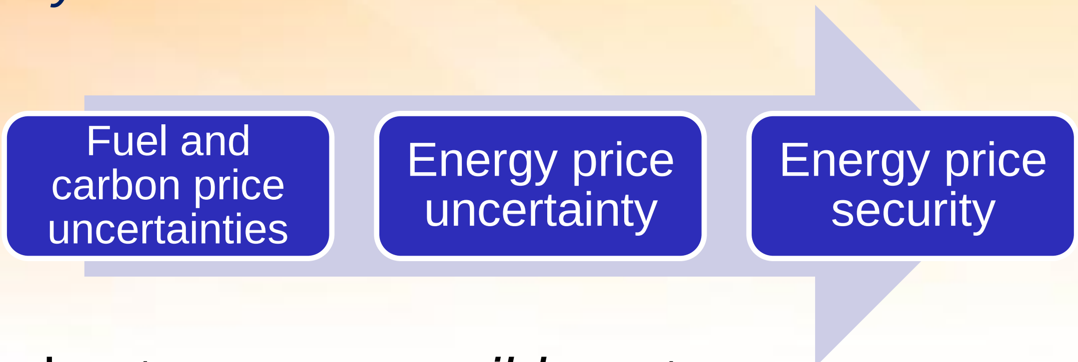
Spot Price of EU Allowances

Source: CARBIX, http://www.eex.com

- IEA modelling of carbon prices is around \$100/tCO_2 by 2040-2050.

Implications of future uncertainties

- Uncertainties in fuel & carbon prices have significant implications for energy security – leads to energy price fluctuations
  - *Price stability has economic value*



- ***Risk*** – *arise* due to *many possible outcomes* as a result of uncertainty.
  - *The likelihood of loss or unexpected high costs (or low returns)*
  - *Risks can be quantified by the spread of a set of possible outcomes.*

- Generation options (or portfolios) that are less exposed to risks and uncertainty help strengthen energy security of a nation.

Existing generation investment frameworks

Existing models such as WASP, MARKAL have significant capabilities and powerful features but…

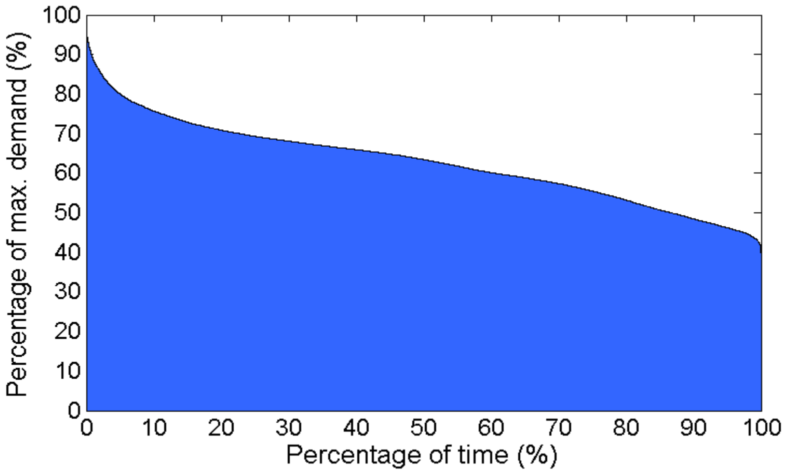
- Focus on finding the least-cost technology (or portfolio mix) based on deterministic assumptions on key cost factors
- Limited treatment of future uncertainty and analysis of risk.
  - *Deterministic assumptions on key factors including future demand, future fuel costs, and construction costs of possible generation investment options.*
- Multiple objectives in generation investment and planning
  - *Costs, risks, CO_2 emissions.*
  - *Potential tradeoff between expected future industry generation costs VS the uncertainty associated with such costs ("cost risks")*

Probabilistic Generation Portfolio Modelling

- A modeling tool to assess many possible future generation portfolios given a range of ***future uncertainties*** and ***multiple criteria objectives***
- Combine three key techniques
  - ***Load Duration Curve (LDC)*** *optimal generation mix concepts.*
  - ***Monte Carlo simulation*** *technique to formally incorporate uncertainties.*
  - ***Generation Portfolio analysis*** *to determine an 'Efficient Frontier' of expected overall costs, associated cost risks and emissions for different generation portfolios*
- Results can be used to explore various issues and tradeoffs between multiple (and conflicting) criteria - costs, associated risks and emissions.
- A range of technologies can be included.

Probabilistic Generation Portfolio Modelling

Load duration curve



MCS process

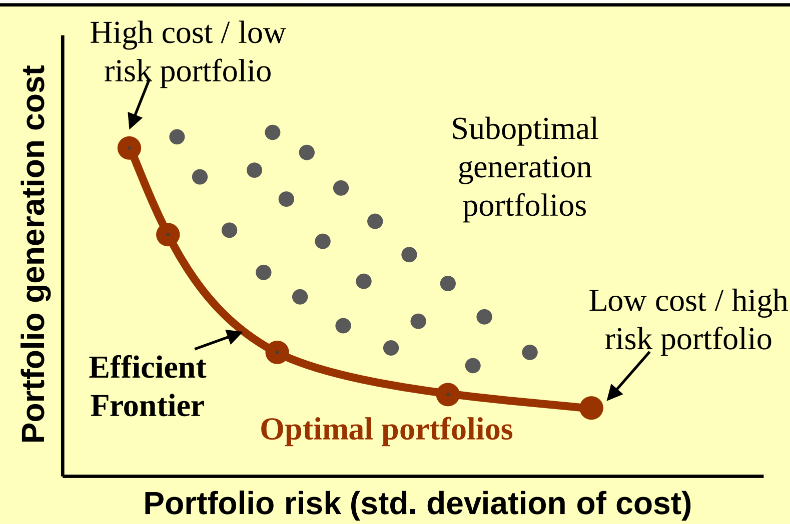
Identify key uncertain variables → Assign probability distributions to the uncertain variables → Generate random samples (i = n samples) → Calculate total costs and emissions → Range of possible results represented by a probability distribution

Output from MCS represented by a prob. distribution - *Mean and SD can be used to measure expected cost and risk profile*

Generation Portfolio Analysis

Expected (mean) cost and cost spread (SD) of each portfolio is plotted to compare tradeoff between ***costs*** VS ***risks***.

Optimal generation portfolios fall along ***"Efficient Frontier"*** *(Costs can only be reduced by accepting higher cost risks).*

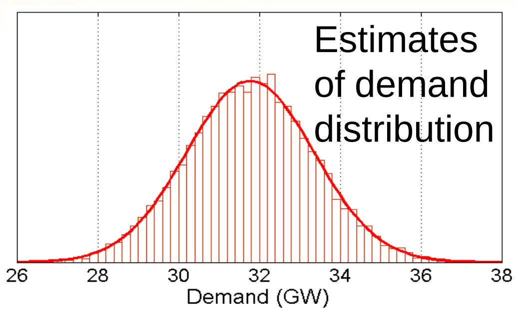


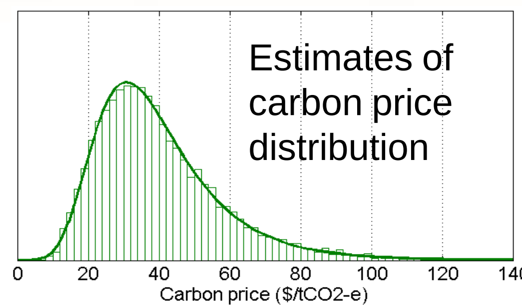
Probabilistic Generation Portfolio Modelling

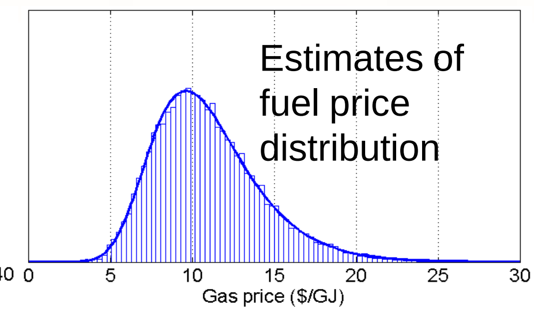
Inputs

- **Generator characteristics of each technology**
  Plant life, cost parameters, Emission factors, operating parameters
- **Demand projection in a future year**
- **Prob. distributions of uncertain parameters**
  - fuel and carbon prices
  - Capital costs
  - Demand

**** Require a set of relatively simple input data**





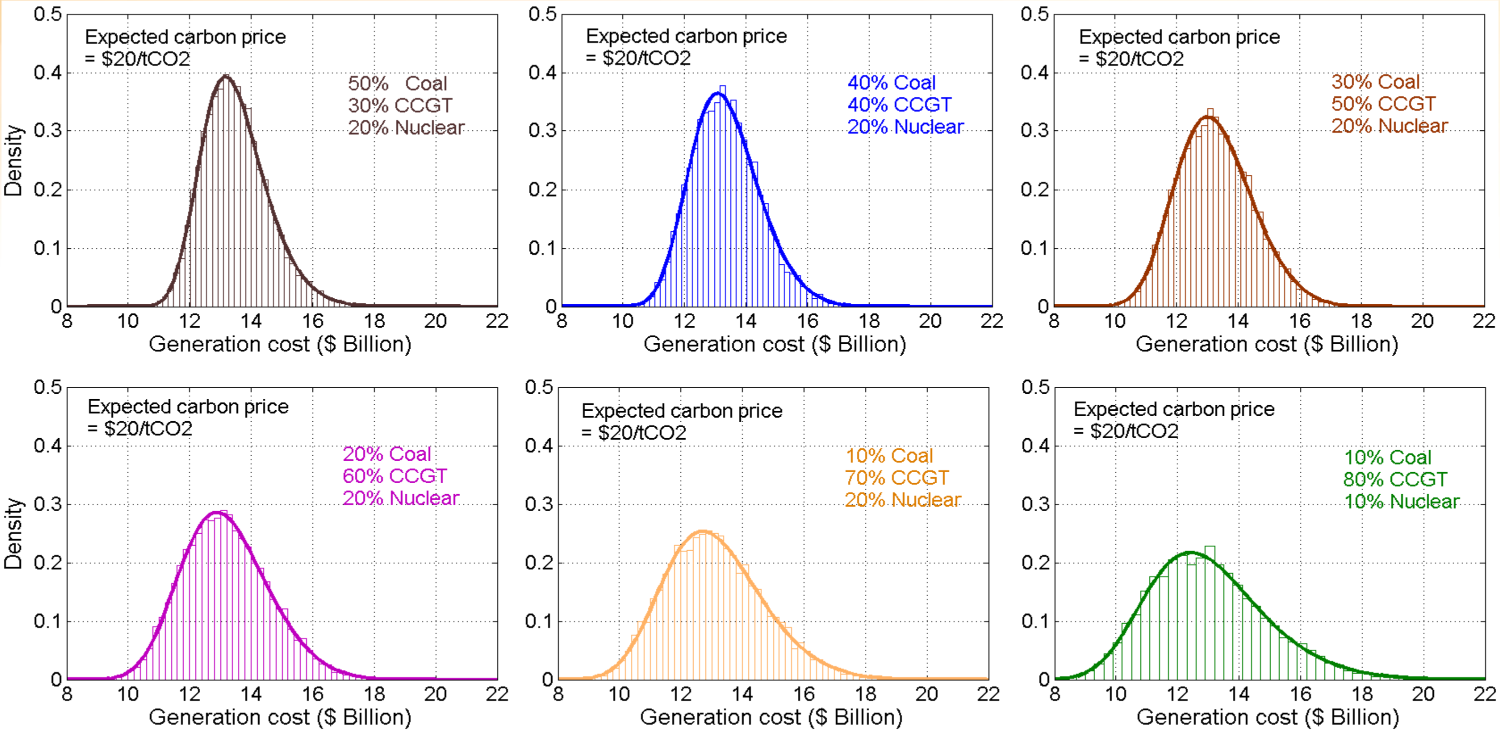


Distributions of uncertain parameters can be estimated based on historical data and informed expert opinions

The model can be calibrated for any electricity industry.

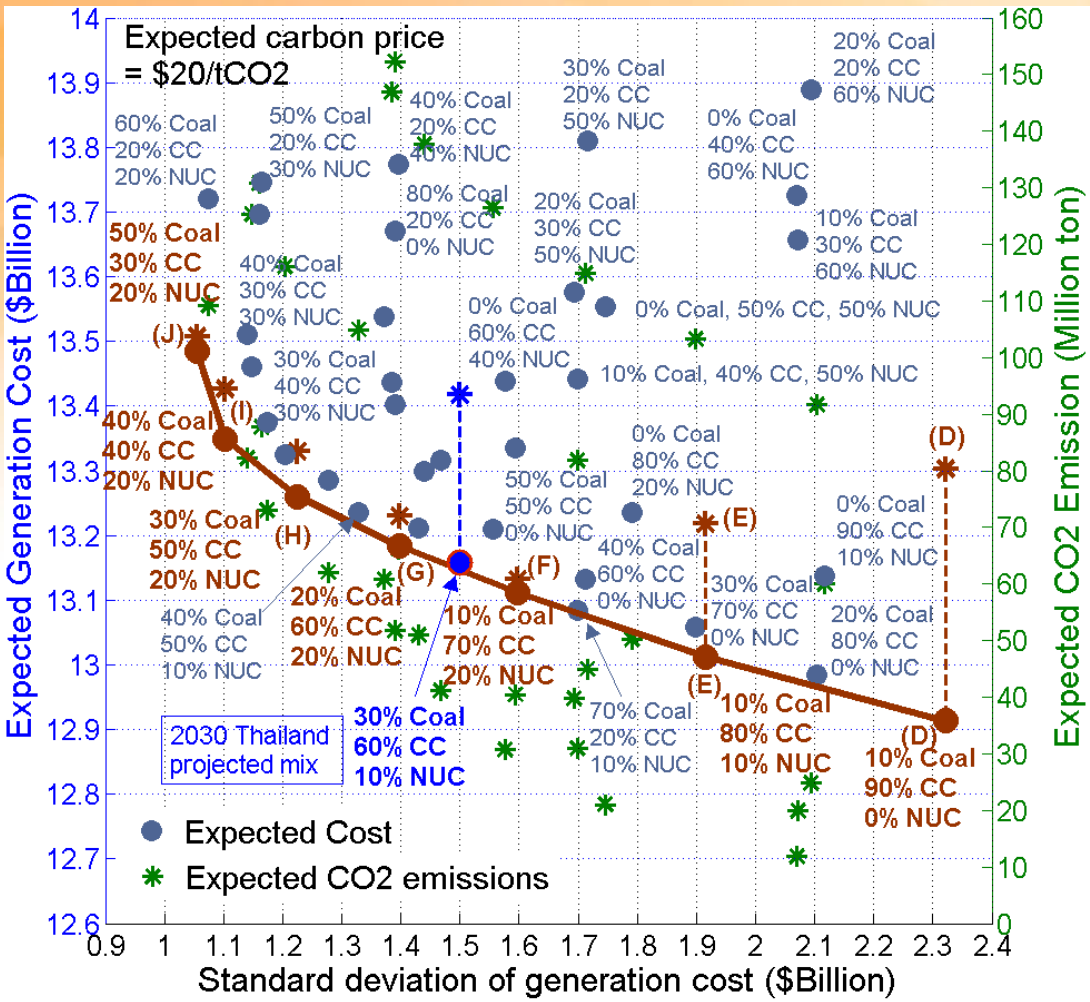
Probabilistic Generation Portfolio Modelling

- **Outputs** provide a full spectrum of possible results
  - ***Annual portfolio generation cost ($ or $/MWh)***
  - ***Cost spread (representing 'cost risk')***
  - ***Emissions***



Examples of generation cost distributions for different generation portfolios.

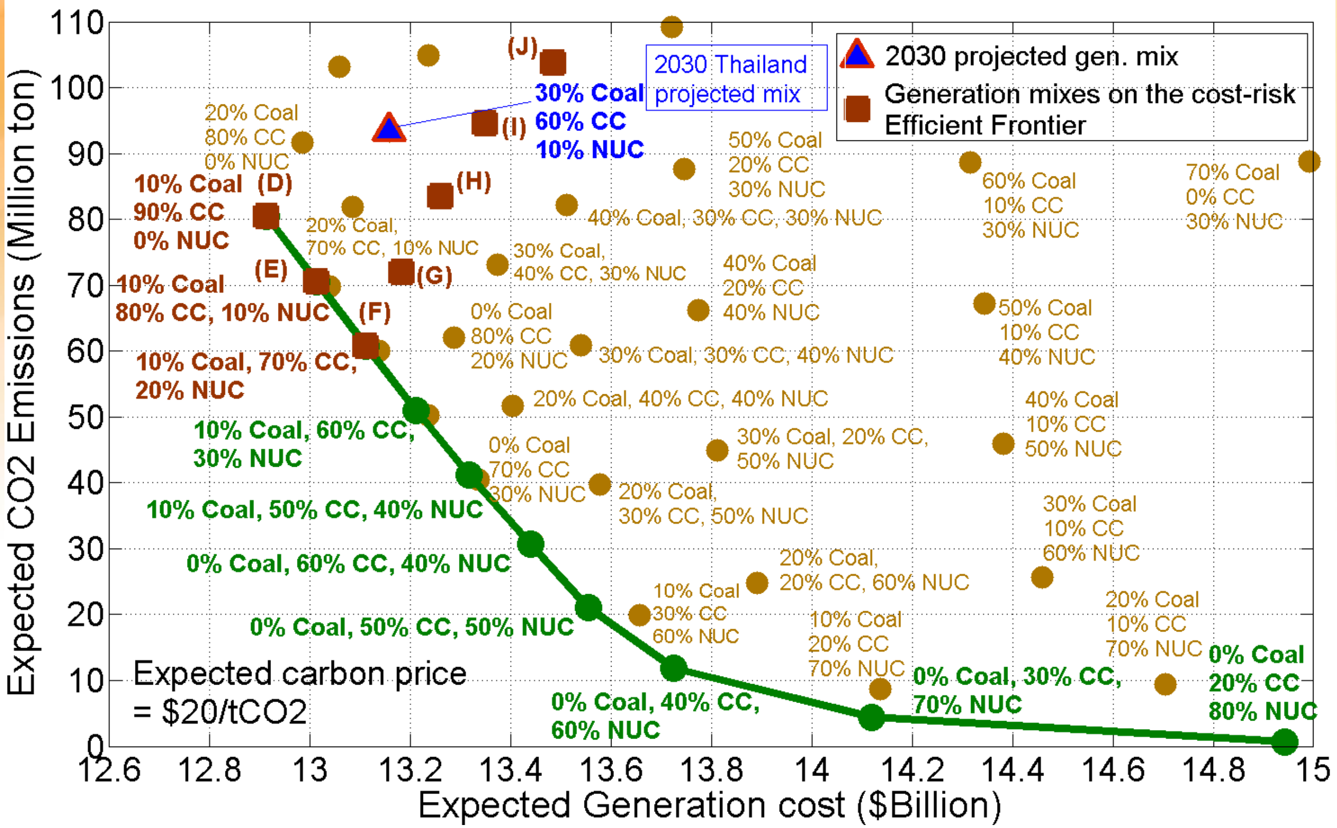
Some examples



Cost, risk (SD of costs) and emissions of every possible generation portfolio mix are plotted

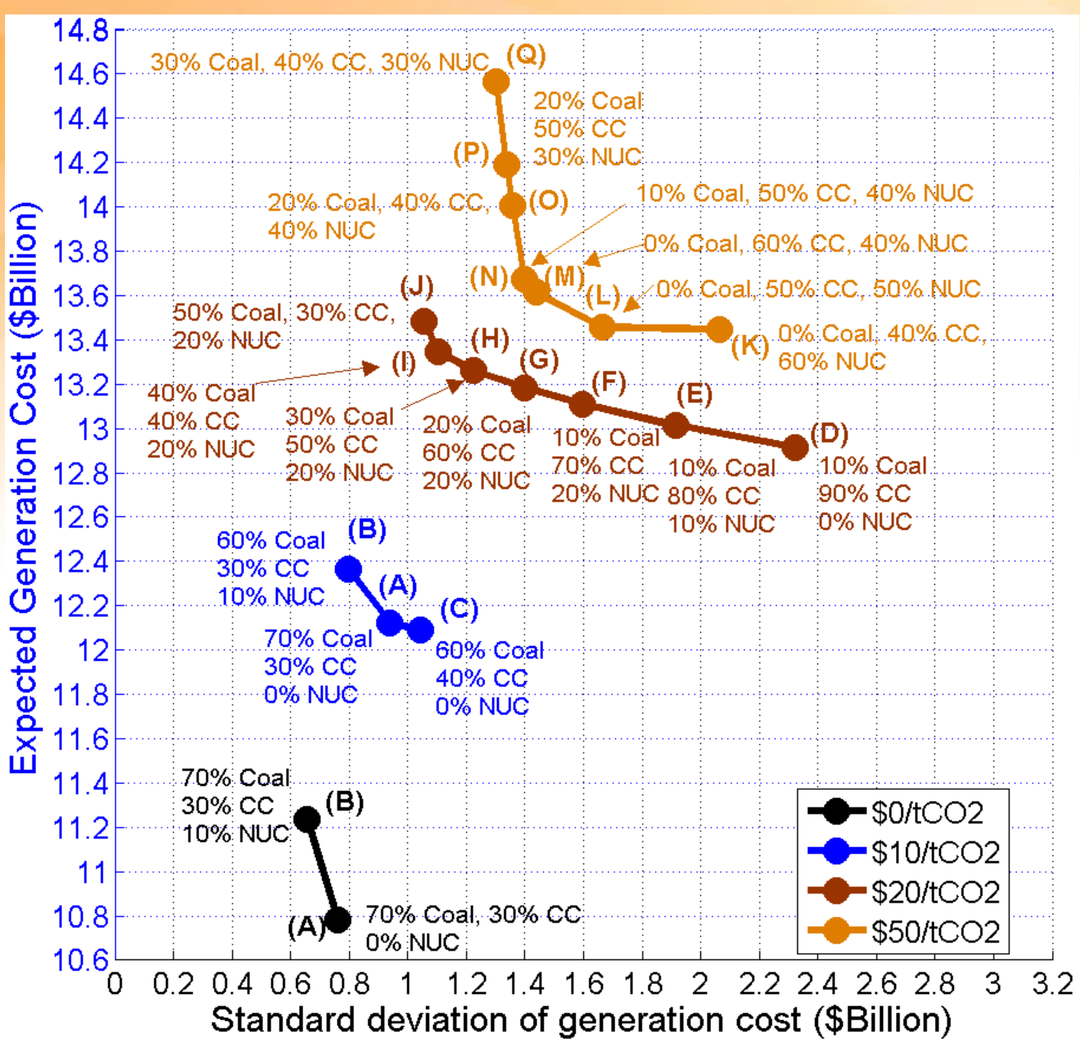
- *Cost-risk Efficient frontier containing optimal portfolios*

Some examples



Efficient frontiers showing tradeoffs between costs and emissions

Some examples



Efficient frontiers for different expected carbon prices

Key aspects of the model

- Simple and transparent – simple input data, reasonable runtime.
- Sophisticate approach to incorporate uncertainty and risk assessment.
- The way results are presented provides a basis for comparing tradeoffs among possible alternative generation portfolios
  - *Rather than focusing only on a particular generation portfolio (e.g. least cost portfolio)*
  - *Taking into account wider multiple criterion electricity industry objectives (i.e. cost, risk and emissions).*

The model is implemented using MATLAB software

Applications of the Model

- The modeling tool has been applied to a number of case studies to explore various issues.
  - *The impact of fuel and carbon price uncertainty.*
  - *The influence of carbon pricing on the level of CO_2 emissions.*
  - *The impact of carbon price on the economic value of renewables.*
  - *The role of nuclear power in future generation portfolios and its dependency of climate policy.*
  - *The potential value of high wind and PV penetration in the Australian National Electricity Market (NEM).*
  - *The role of renewables in mitigating the impact of uncertainty.*
  - *Analysis future generation portfolios in Thailand*
- Helps facilitate energy and climate policy decision making.

Current work

- Exploring *investment and policy support frameworks for facilitating high RE penetrations in Australia's EI*
  - *Extending and applying the modelling tool to analyse different policy options and scenarios including DSP, RETs etc.*
  - *Identifying opportunities and challenges for driving investment and facilitating the integration of RE into future generation portfolios.*
  - *Key focus is on maximising synergies*
    - *Synergies among RE technologies and other technology developments such as EV and storage.*
    - *Synergies between multiple RE policy instruments*
- Applying the modelling tool to analyse
  - *Revenue and profit of generators in the NEM*
  - *The impact of gas price uncertainty on future generation portfolios in the NEM*

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