Modelling Electricity Generation Investment and Carbon Price

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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.

- 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).

![World CO₂ emissions by sector in 2010](source: 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 to increase by 4,000GW

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

<table>
<thead>
<tr>
<th>Technology</th>
<th>Capital cost</th>
<th>Operating cost</th>
<th>Emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal-fired</td>
<td>High</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>CCGT</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
</tr>
<tr>
<td>OCGT</td>
<td>Low</td>
<td>High</td>
<td>Moderate</td>
</tr>
<tr>
<td>Nuclear</td>
<td>Very high</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Renewables</td>
<td>High</td>
<td>Very low</td>
<td>None</td>
</tr>
</tbody>
</table>
Generation investment decision-making

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

  - Tradeoffs (Synergies)

  Overall industry costs

  - Coal? gas-fired?

  Energy security
  - Physical supply
  - Price stability

  Objectives

  Environmental emissions
  - CO₂
  - NOₓ
  - SOₓ

  - Tradeoffs (Synergies)

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

Revised annual energy growth rates (NEFR, 2012)
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**

- IEA modelling of carbon prices is around $100/tCO₂ 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
  - 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, CO₂ 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**

<table>
<thead>
<tr>
<th>Percentage of max. demand (%)</th>
<th>Percentage of time (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
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<td>20</td>
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<td>90</td>
<td>90</td>
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<tr>
<td>100</td>
<td>100</td>
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**MCS process**

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

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
- Demand projection in a future year
- Prob. distributions of uncertain parameters
  - fuel and carbon prices
  - Capital costs
  - Demand

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\textsubscript{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
Thank you, and Questions?
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