Uncertain energy pathways in the 2020s to meet long term carbon abatement targets

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Introduction

- Stochastic programming
- Stochastic MARKAL
- Preliminary results
- Hints and tips for using Stochastic MARKAL
- Conclusions
Issues with deterministic transition scenarios

• Each deterministic scenario has a different solution
  – Investment decisions depend on investor's perspective of the future

• How to arrive at a common course of action given multiple possible future scenarios?
  – A least-cost transition to a low carbon future under uncertainty

Stochastic Programming (1)

What is Stochastic Programming?

• Takes account of uncertainty
• What decision will perform well on average?
• Results include: (Shapiro et al. 2007)
  – ONE Hedging strategy
  – MULTIPLE Recourse strategies (one for each SOW)
  – Metrics
    • EVPI – expected value of perfect information
    • ECIU – expected cost of ignoring uncertainty

• Insights differ from previous 'comparison of deterministic runs'
  – What are the robust technologies under uncertainty?
2 main challenges with future scenarios

1. There are a huge number of uncertainties in the future energy system
   - It is very difficult to represent all of these using stochastic programming
   - **Use scenarios** – elicit ‘expert opinion’
     - Number of scenarios increases exponentially with the number of random variables
   - **Use a Monte Carlo approach to create a sample of future scenarios**

2. How to measure ‘quality’ of the results from these scenarios with respect to ‘true optimum’?

Shapiro et al. 2007

**Stochastic MARKAL (1)**

- Two stage
- Limited to nine states of the world

![Diagram of Stochastic MARKAL (1)]
A different Objective Function

$$\text{Exp}_\text{Cost}_{[\text{sow}]} = \sum (-\text{D.MED.OBJ} + \text{D.TOT.TAXSUB})_{[\text{sow}]}$$

$$\text{Expected Cost}_{\text{Scen}} = \sum (\text{Cost}_{\text{SOW}} \times \text{Prob}_{\text{SOW}})_{[\text{sow}]}$$

- Expected Cost of a scenario is the sum of all probability weighted costs of the hedging strategy and future states of the world.
- Alternative is Expected Utility
  - not yet using at UCL
  - minimises variation in cost of scenarios according to a risk averse investor.
UK Policy Context

• Legally binding 80% CO₂ reduction target
• Considerable UK Government rhetoric
  – “The Government is committed to playing its part in moving to a low-carbon economy... As part of this, the UK needs £200 billion of investment to 2020 to provide secure low-carbon energy...” HMRC, June 2010 Budget Statement
• Strong history of energy systems models informing policy decisions
  – E.g. Energy White Paper 2003, Climate Change Act

Question?

• Given uncertainty in the future UK energy system…
• …What is the optimum near term strategy?
• Interested in time period – 2010 to 2025
  – This is the hedging strategy
Uncertainties

- Availability and cost of new technologies
  - Low carbon electricity (wind/nuclear/CCS)
  - Hydrogen vehicles
  - Heat pumps/solid wall insulation
- Build rates of new infrastructure and technologies
- Price and availability of
  - fossil fuel resources
  - biomass resources
- Future demands for energy services, price elasticity of energy service demands
- UK emissions targets

Key Assumptions

- See documentation (Kannan et al. 2007) for UK MARKAL structure and data assumptions
- 80% CO₂ reduction target
- Stochastic + Elastic Demand mode
- Four fossil fuel price scenarios (coal, oil, natural gas) from 2030 to 2050. Central prices to 2025.
  - Low
  - Central
  - High
  - High high
- Equal probabilities assigned to each fuel price
Difference from reference scenario:
Primary Energy at end of hedging strategy

Resource prices (2)

Primary Energy at end of model horizon (diff.)
Resource prices (4)

Electricity Output by Technology at end of hedging strategy – 2025 (diff.)

Resource prices (5)

Electricity Output by Technology at end of model horizon – 2050 (diff.)
Annual consumption of primary biomass (difference from ref. scenario)

Resource prices (6)

Resource prices (7)

Welfare cost
General insights from stochastic MARKAL

- The modelled UK energy system appears to have some inertia
  - hedging strategies are relatively minor
- Deterministic central case seems to be a good approximation of hedging strategy (in most cases)

Expected Value of Perfect Information

\[ EVPI = \text{COST}_{\text{hedge}} - \sum_{i=1}^{4} p_i \cdot \text{COST}_{\text{PFI}} \]

<table>
<thead>
<tr>
<th>Scenario</th>
<th>EVPI (2000£M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>265</td>
</tr>
<tr>
<td>Tech Failure</td>
<td>427</td>
</tr>
<tr>
<td>Demand</td>
<td>462</td>
</tr>
</tbody>
</table>

- What is the value of knowing about the future NOW?
- Or, the cost handicap introduced by uncertainty
Advice for using stochastic MARKAL

• SOW1 overrides other SOWs
  – Can result in incorrect comparisons
  – Leave out data in SOW1 before resolution period

• When using Stochastic + Partial Equilibrium, a decision must be made about base prices
  – Base prices should correspond to data in SOW1
  – Be clear about what is being compared

• Bugs
  – E.g. Do not use BOUND(BD)O constraints for externally load managed (XLM) technologies
    • Use BOUND(BD) instead

Advice for using stochastic MARKAL (2)

• Decide how your constraint and timing relates to your Resolution of Uncertainty period
  – Does the model jump to required value?
    • Is it feasible?
    • How does it affect the hedging strategy e.g. If extreme cost
  – Is it an increase to a value from a common centre?

• The distribution of future scenarios should be internally consistent
### References

Loulou, R., Goldstein, G., Noble, K. 2004 Documentation for the MARKAL Family of Models


### Useful links

www.stoprog.org – A very useful page introducing stochastic programming with applied examples

### Appendix A

**ANSWER Stochastic Results Parameters**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>D.MED-TESCST</td>
<td>D.MED.OBJ - D.MED-SURF.RED + D.MED-SURF.GRO</td>
</tr>
<tr>
<td>D.MED-TESCSTDIF</td>
<td>D.MED-REF.OBJ - D.MED-SURF.RED + D.MED-SURF.GRO + D.MED-OBJ</td>
</tr>
<tr>
<td>D.MED-TESCSTDIF</td>
<td>D.MED-REF.OBJ + D.MED.TESCST</td>
</tr>
<tr>
<td>D.MED.CPSURPLUS</td>
<td>D.MED-OBJ + D.MED-REF.OBJ</td>
</tr>
<tr>
<td>D.MED.CPSURPLUS</td>
<td>D.MED-SURF.RED + D.MED-SURF.GRO - D.MED.TESCSTDIF</td>
</tr>
<tr>
<td>D.MED.CPSURPLUS</td>
<td>D.MED-SURF.RED + D.MED-SURF.GRO - D.MED.TESCST + D.MED-REF.OBJ</td>
</tr>
<tr>
<td>Objective Function for each SOW</td>
<td>D.MED.TESCST+ D.TOT.TAXSUB + D.MED-SURF.RED - D.MED-SURF.GRO</td>
</tr>
<tr>
<td>or by substitution:</td>
<td>D.MED.OBJ + D.TOT.TAXSUB</td>
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