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

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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) UCL

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?

Stochastic Programming (2)

2 main challenges with future scenarios

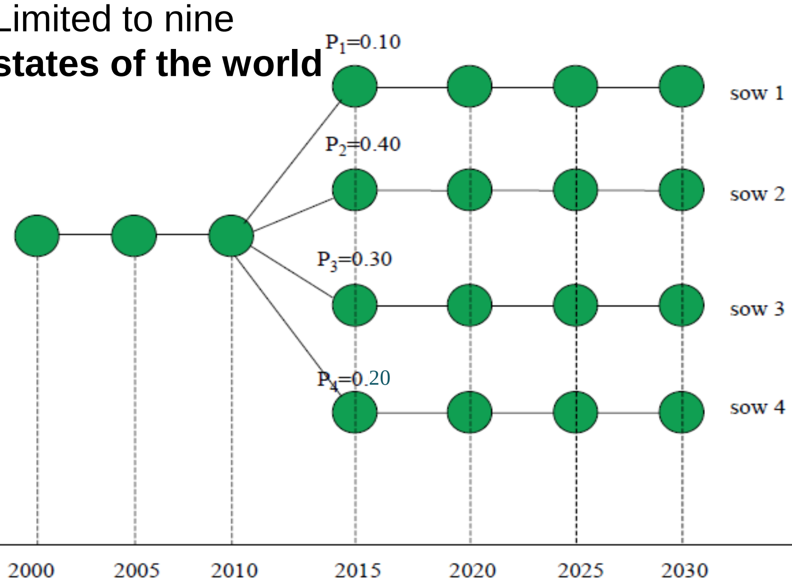
1. There are a huge number of uncertainties in the future energy system
   - It is very difficult to represent all of these using stochastic programming
   - **Use scenarios – elicit 'expert opinion'**
     - Number of scenarios increases exponentially with the number of random variables
   - **Use a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

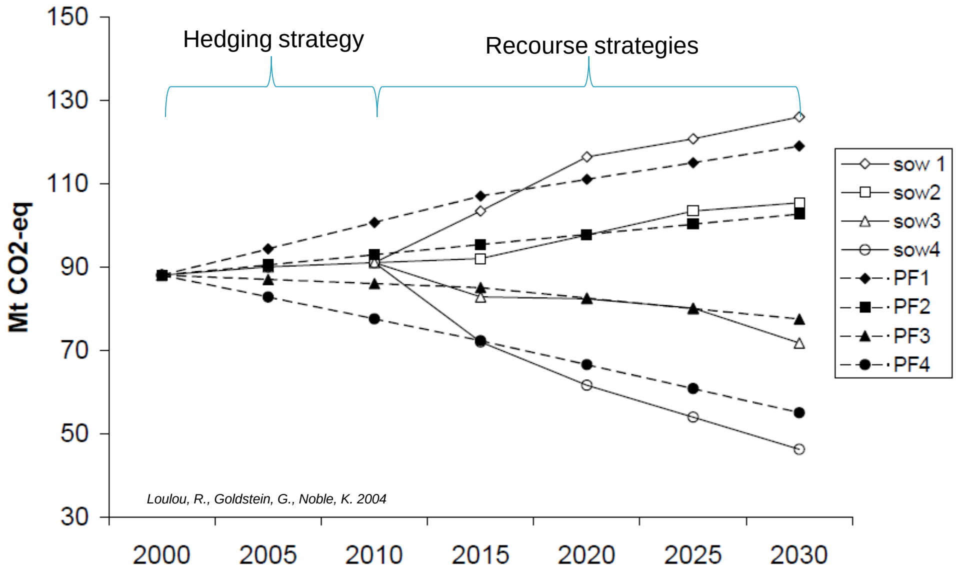
Loulou, R., Goldstein, G., Noble, K. 2004

- Two stage
- Limited to nine **states of the world**



Stochastic MARKAL (2)

GHG emission trajectories



Stochastic MARKAL (6)

A different Objective Function

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

$$\textit{Expected Cost}_{Scen} = \sum(Cost_{SOW} * Prob_{SOW})$$

- 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

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UK Policy Context

- Legally binding 80% CO_2 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

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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

Defining stochastic scenarios

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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 ✓

Resource prices

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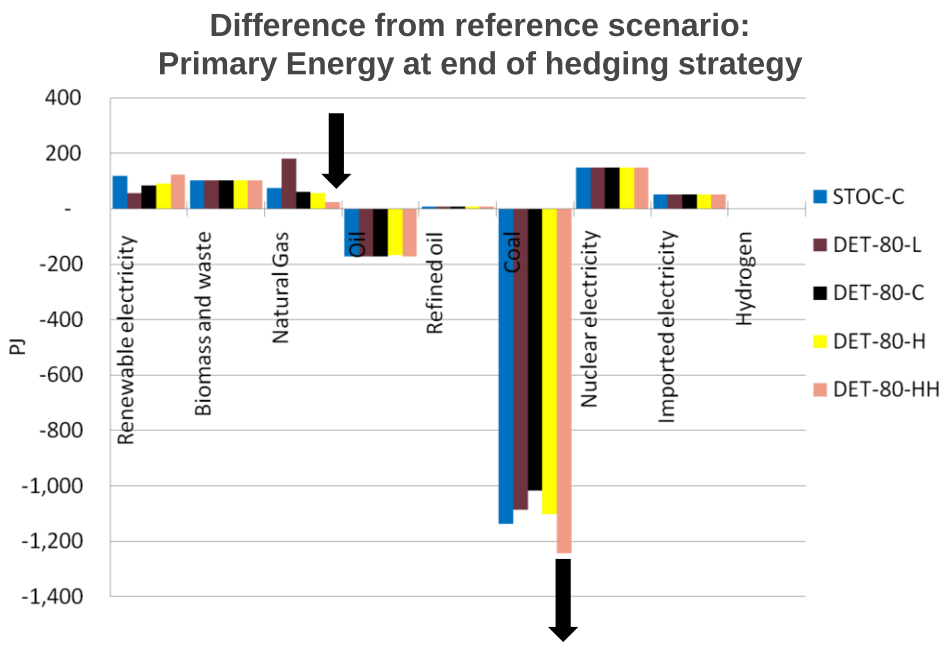
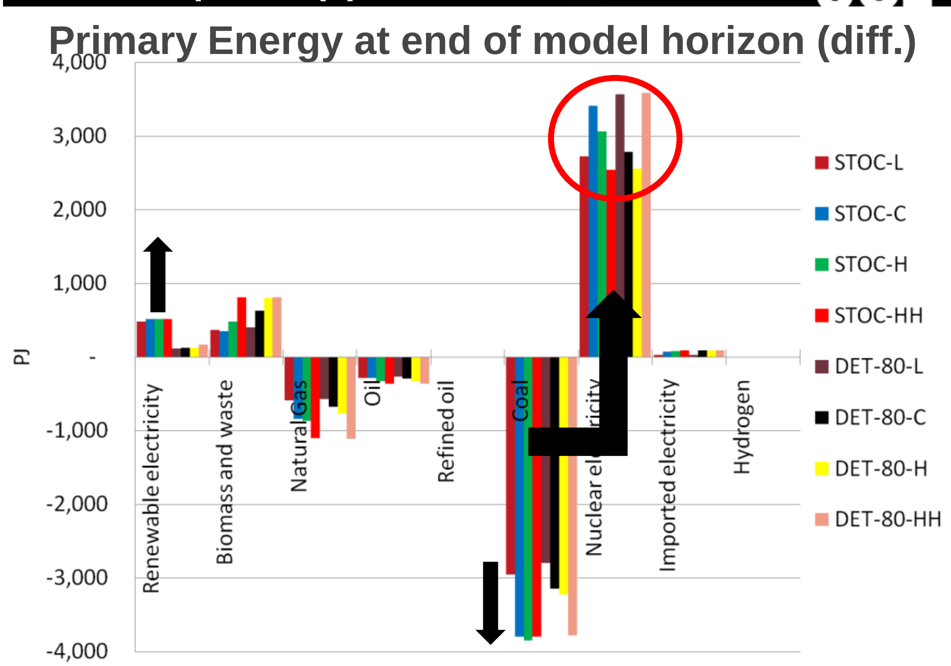
Key Assumptions

- See documentation (Kannan et al. 2007) for UK MARKAL structure and data assumptions
- 80% CO_2 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

Resource prices (2)

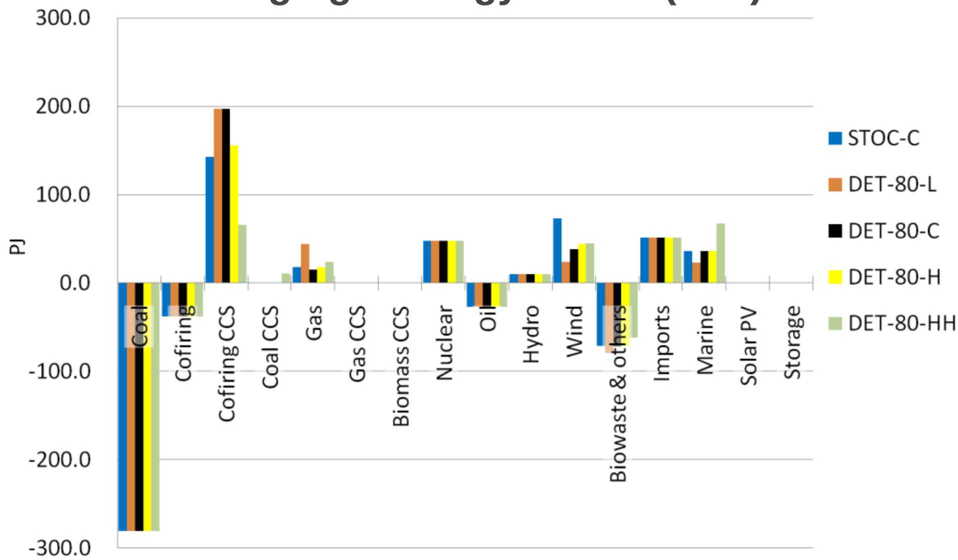


Resource prices (3)



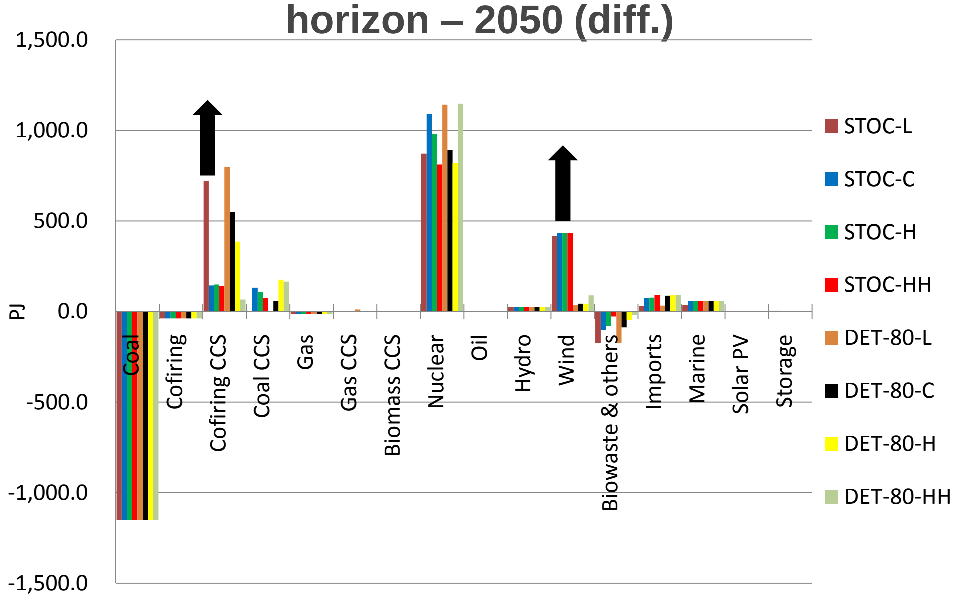
Resource prices (4)

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.)



Resource prices (6)

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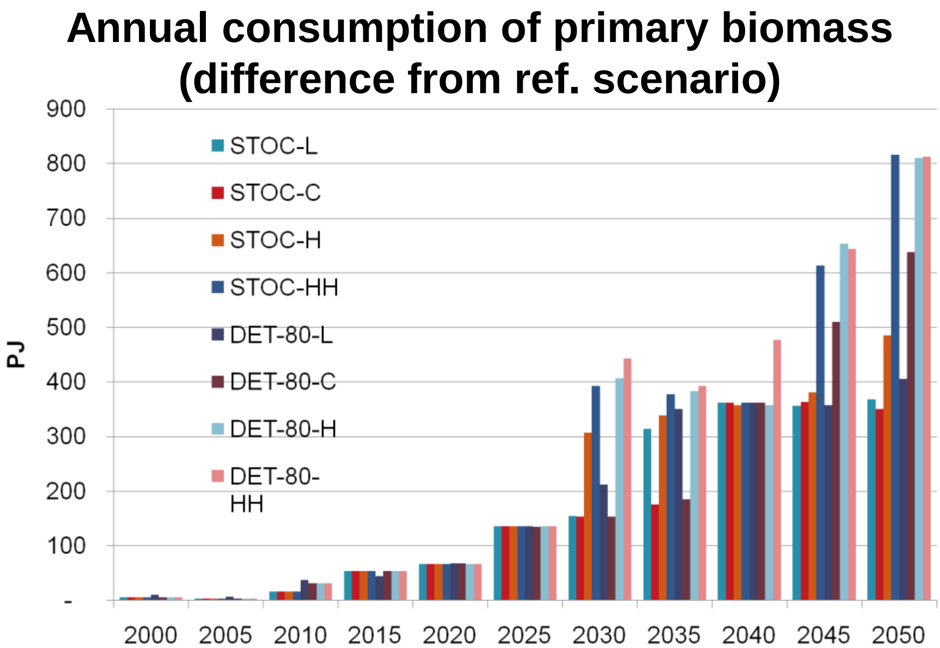

Resource prices (7)

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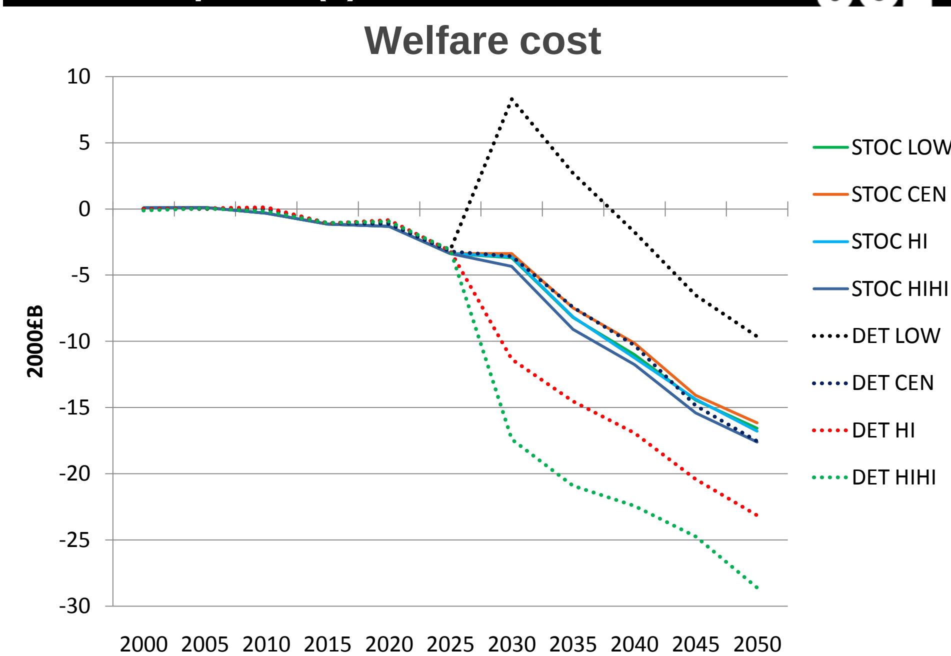

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General insights from stochastic MARKAL

- 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)

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Expected Value of Perfect Information

$$EVPI = COST_{hedge} - \sum_{i=1}^{4} p_i \bullet COST_{PFi}$$

Loulou et al., 2004

Scenario	EVPI (2000£M)
CO_2	265
Tech Failure	427
Demand	462

•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

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References

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

Shapiro, A., Andy Philpott, A. 2007 *A Tutorial on Stochastic Programming, Available From:* http://stoprog.org/SPTutorial/SPTutorial.html Accessed: 19th June 2010

Kannan, R., Strachan, N., Pye, S., Balta-Ozkan, N., 2007. *UK MARKAL Model Documentation*. Available from: www.ukerc.ac.uk

Useful links

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

Appendix A

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ANSWER Stochastic Results Parameters

D.MED-TESCST	- D.MED.OBJ - D.MED-SURF.RED + D.MED-SURF.GRO
D.MED-TESCSTDIF	- D.MED-REF.OBJ - D.MED-SURF.RED + D.MED-SURF.GRO + D.MED-OBJ
D.MED-TESCSTDIF	- D.MED-REF.OBJ + D.MED.TESCST
D.MED.CPSURPLUS	- D.MED-OBJ + D.MED-REF.OBJ
D.MED.CPSURPLUS	- D.MED-SURF.RED + D.MED-SURF.GRO - D.MED.TESCSTDIF
D.MED.CPSURPLUS	- D.MED-SURF.RED + D.MED-SURF.GRO - D.MED.TESCST + D.MED-REF.OBJ
Objective Function for each SOW	D.MED.TESCST+ D.TOT.TAXSUB + D.MED-SURF.RED - D.MED-SURF.GRO
or by substitution:	- D.MED.OBJ + D.TOT.TAXSUB