Modelling Long-term Carbon Abatement Scenarios with UK MARKAL

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6th BIEE Academic Conference, Oxford
20-21 September 2006
Outline

- Introduction
- Modelling and Results
- Comment and Interpretation
- Discussion
2006 UK MARKAL model

- MARKet ALLocation dynamic optimization model
- Dynamic optimization based on life-cycle costs of competing technologies and pathways
- Consistent and flexible what-if framework
  - Updated technology data
  - Resource supply curves (domestic and import)
  - Detailed infrastructure representation
  - Detailed technology pathways
    - nuclear cycles, biomass, hydrogen, refining,
  - Electricity sector
    - Grid representation, CO$_2$ storage, micro-gen
  - End-use detail
    - Industry, transport, residential, service sector
  - Full MACRO module
    - Demand response; GDP impacts
Modelling principles

• Openness and transparency
  - Explicit assumptions and justifications

• Fully documented data sources
  - Validation sought from stakeholders

• Explicit sensitivity and uncertainty analysis
  - Thresholds & tipping points that favor one technology pathway or another
  - Important interactions and tradeoffs
  - Flexibility available in meeting goals
  - Robustness of results or outcomes

• Construction of consistent and policy relevant scenarios for evaluating the UK energy system
Model and data validation

- Model reports and documentation made available at: www.ukerc.ac.uk/content/view/142/112
- Stakeholder workshops
  - Electricity generation: DTI, 10th April 2006
  - Road transportation: DfT, 16th March 2006
- Bilateral peer reviews
  - Hydrogen: David Joffe, Imperial College and UKSHEC
  - Nuclear: Paul Howarth, Dalton Institute, University of Manchester
  - Biomass: Ausillio Bauen, Imperial College and TSEC BIOSYS
  - Carbon capture: David Reiner, University of Cambridge and UKCCSC
- Data sensitivity analysis
  - Derek Smith, PSI Visiting Fellow
- Initial model peer review
  - Gerard Martinus, ECN Policy Studies, Netherlands
CAVEAT 1

DRAFT RESULTS
## Input Summary for MARKAL Base-case and 60% CO₂ Constrain Scenario

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value / Source</th>
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<tbody>
<tr>
<td>Time frame</td>
<td>2000-2050, in 5 yearly intervals</td>
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| Discount rate                    | Global 10%: Market investment rate  
                              End-use sectors 25%: Increased payback period requirements                                                                 |
| Fuel prices                      | DTI (2006) Base import level; import and domestic stepped supply curves                                                                                                                                 |
| Energy demands                   | DTI (2006): Includes CCP and CCPR through 2020; low growth projection through 2070                                                                                                 |
| Calibration                      | DUKES (2005): Final energy, primary energy, CO₂ emissions, electricity generation, fuel resources, aggregate and sectoral disaggregation (within 2%)                                    |
| Sectoral coverage                | Industry (sub-sectors include chemicals, iron and steel, paper and pulp, non ferrous metals and other industry), services, residential, transport, agriculture, own energy industry use  
                              Non-energy fuel use not considered                                                                                                                                                  |
| Load profiles                    | Actual year 2000 electricity and heat load profiles (National Grid, 2006)                                                                                                                  |
| Taxation and policy measures     | Included: CCL, hydrocarbon duty, transport fuel duty  
                              Not included EU ETS, LCP directive, and renewables targets (electricity and road)                                                                |
| Emissions                        | SO₂ & CO₂ additionally tracked by sector (electricity separately, or assigned to end-use sector)                                                                                      |
| Emissions trajectory             | 30% reduction from 2030; linear trend to 60% reduction from 2050                                                                                                                        |
| Technology treatment             | Vintages for process, electricity, industrial transport, residential and commercial technologies                                                                                         |
|                                  | Exogenous learning curves for early technologies in electricity, transport and hydrogen  
                              All data corresponds to latest iteration                                                                                                                                 |

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*UK ERC*
Energy Service Demands

- Domestic air energy service demands
- Car transport energy service demands

UK ERC

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Base Fuel Prices

DTI base fossil import prices

- Natural gas
- Coal
- Oil

£/GJ

CO₂ emission levels

![Graph showing CO₂ emission levels from 2000 to 2050 with two lines: one for Base-case and one for CO₂ 60% reduction.]

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Total Primary Energy

Total primary energy

petajoules (PJ)

0 2,000 4,000 6,000 8,000 10,000 12,000


Base
CO2-60
Base-case: production, imports, exports

Base case energy balance
60% CO\(_2\) case: production, imports, exports

CO\(_2\) 60% constrained case energy balance
Base-case: electricity output

Base-case - Electricity by fuel

- Solar
- Bio + waste fuels
- Wind
- Hydro
- Nuclear
- Oil
- Gas
- Coal cofire
- Coal

petajoule (PJ)

60% CO₂ case: electricity output

60% constraint-case - Electricity by fuel

- Solar
- Bio + waste fuels
- Wind
- Hydro
- Nuclear
- Oil
- Gas CCS
- Gas
- Coal CCS
- Coal cofire
Base-case: private road transport technology diffusion

Base case car technologies

- Petrol Hybrid
- Petrol
- Diesel
- Electric

B.v.km

60% CO$_2$ case: private road transport technology diffusion
Residential and services: conservation measures

Uptake of conservation measures

- Base case
- CO2-60%

Petajoules (PJ)

Sectoral CO₂ reduction: (electricity and hydrogen assigned to end-uses)
Total energy system costs

Undiscounted 2050 abatement cost is £8.2B
Marginal CO₂ prices

2050 CO₂ price at £152/TCO₂ or £557/TC

CO2 abatement prices

GBP / TCO₂

0 20 40 60 80 100 120 140 160


CO₂ marginal price
CAVEAT 2

SENSITIVITY ANALYSIS!!
Parametric & probabilistic
Initial list of modelling insights

- Baselines are crucial (low growth in this case)
- Energy imports are substantial and growing
- All sectors contribute to abatement
- Coal and CCS are key electricity base-load techs
- Renewables are key peaking and shoulder techs
- Comparatively less take-up of conservation
- CO₂ emission price signals are significant
Implications for policy and decision making

- Models are not truth machines. They are intended to stimulate thought and deliver insights into complex realities.
- Difference between:
  - Forecasts - derived from past trends, theory
  - Scenario projections - derived from input assumptions
- Importance of uncertainty/sensitivity analysis, ranges (rather than point estimates) of data
- Good models are GIGO (Garbage In, Garbage Out): crucial importance of transparent assumptions and sourced data (with ranges)
- Models should not be used to justify prior preferences or decisions (but can all too easily be used in this way)
- Importance of model evaluation: UKERC ESMT aspires to provide this over the medium term.
Thank you

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