Introduction

Overview

MARKAL (an acronym for MARKet ALlocation) is a widely applied bottom-up, dynamic, linear programming (LP) optimisation model. It supported by the International Energy Agency (IEA) via the Energy Technology and Systems Analysis Program (ETSAP). It is being used by around 100 active teams in over 30 countries, and has a long track record of policy and academic research.

MARKAL portrays the entire energy system from imports and domestic production of fuel resources, through fuel processing and supply, explicit representation of infrastructures, conversion to secondary energy carriers (including electricity, heat and hydrogen), end-use technologies and energy service demands in the industrial, commercial, residential, transport and agricultural sectors. The model structure and individual modules are detailed in Chapter 2 and Chapters 3-10 respectively.

One strength of UK MARKAL is the development of model variants to investigate key policy and research issues that require a hybrid or more detailed approach. These include the calculation of macro-economic impacts via integration with a neoclassical growth model (MARKAL-Macro); as well as endogenous behavioural change in energy service demands via dual optimization (MARKAL Elastic Demand) of energy supply and demands. Additional variants include spatially and temporally detailed versions to investigate infrastructure development and energy storage respectively, as well as MARKAL LCS (international drivers), MARKAL AQ (local air pollutants), stochastic MARKAL, MARKAL biomass and MARKAL hydrogen. Model variants are discussed in Chapter 10.

The choice to use a particular energy-economic-engineering-environment (E4) model (or variant) depends on the answers sought and the quality of available data. The UK MARKAL model family, as a partial equilibrium energy system and technologically detailed model, is well suited to investigate the economic, social, and technological trade-offs between long-term divergent energy scenarios.

Model Methodology

MARKAL optimises (minimises) the total energy system cost by choosing the investment and operation levels of all the interconnected system elements. The participants of this system are assumed to have perfect inter-temporal knowledge of future policy and economic developments. Hence, under a range of input assumptions, which are key to the model outputs, MARKAL delivers an economy-wide solution of cost-optimal energy market development. In order to replicate the physical, regulatory and policy aspects of the whole UK energy system in MARKAL, many constraints are introduced to the model.

These are designed such that the optimisation of the model database of technological pathways occurs under a realistic engineering and economic framework of the deployment of new infrastructures, fuels and technologies. The model is calibrated DUKES (2006), Digest of United Kingdom Energy Statistics, BERR, London. (including relevant published chapters and internet available.

The model solves in 5-year time steps (through to 2050) for an optimal evolution of energy pathways and technology deployment and use, taking into account:

- Retirement of existing energy capital
- Changing energy resources supply curves (domestic and imported)
- Exogenous trends in energy service demands
- Changing technology costs (via vintaging and exogenous learning curves)
- Alternate energy chain configurations
- Physical constraints within the model
- Policy induced constraints within the model
- Taxes and subsidies

(And in M-M, MED) varying energy service demands

MARKAL generates a detailed set of outputs to characterise the evolution of the UK energy system. Key outputs include energy system costs, fuel and technology mixes, imports, exports and domestic production of resources, electricity generation and capacity investments, marginal costs of fuels including seasonal/diurnal detail of electricity and heat, environmental emission levels (notably CO₂ and SO₂), emission shadow prices, use of infrastructures, and refinery details. Furthermore, when the model is run in MED mode, resultant demand levels are a key model variable, while the M-M variant generates detail on GDP, investment, and consumption at the economy level.

A key attribute of the MARKAL optimisation process is a systematic approach to uncertainty. This is achieved through a “what-if” analysis that seeks to quantify sensitivities and tipping-points of moving between technology categories and energy pathways. Uncertainty is further explored through the use of the stochastic variant of UK MARKAL.

UK Model Development

The development of the UK MARKAL model (2006-2008) has been enabled through the energy systems modelling theme of the UK Energy Research Centre (UKERC), and then led by the research team at Kings College London (KCL); Dr. Neil Strachan, Ramachandran Kannan, Dr. Gabriel Anandarajah and Nick Hughes. The KCL team was supported by a consortium of UK research organizations in continued development and application of the model.

As of 2011, further development of the UK MARKAL has been enabled through Phase II of the UK Energy Research Centre, led by the research team at University College London (UCL); Dr. Neil Strachan, Dr. Gabriel Anandarajah, William Usher, Dr. Paul Dodds, Fabian Kesicki.
The twin objectives of this UK MARKAL modelling consortium are:

1. To maintain the UK MARKAL model's transparency, peer review and open access.
2. To ensure that in iterative updates there is only one core model structure and data-base of the UK MARKAL model family, thus avoiding competing models.

Founding institutions (and contacts) are:

- King's College London (KCL): Dr Neil Strachan and Ramachandran Kannan
- AEA Energy and Environment (AEA): Steve Pye and Nikolas Hill
- Policy Studies Institute (PSI): Dr Nazmiye Ozkan
- Imperial College (IC): Sophie Jablonski
- University of Oxford (UO): Dr Christian Brand

Table I-1: The chronology of UK MARKAL updates

<table>
<thead>
<tr>
<th>Version</th>
<th>Project</th>
<th>Synopsis of changes</th>
</tr>
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<tbody>
<tr>
<td>3.22</td>
<td>UKERC 2050</td>
<td>Build constraints, CCS costs &amp; eff</td>
</tr>
<tr>
<td>3.23</td>
<td>CCC 2010 Stage 1</td>
<td>Recalibration to FE and CO2, CO2 accounting, non-energy</td>
</tr>
<tr>
<td>3.24</td>
<td>CCC 2010 Stage 2</td>
<td>Industrial CCS, bio-methane, hurdle rates, biomass LCA</td>
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<tr>
<td>3.26</td>
<td>AEA DECC 2050 P'ways</td>
<td>Demands, transport eff, hurdle rates, elec inv. costs</td>
</tr>
<tr>
<td>3.27</td>
<td>New UKERC 2050 scen.</td>
<td>UK policy, hurdle rates</td>
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</tbody>
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UK Model Vintages and Alternate Data

The UK MARKAL model and its variants have been applied to a wide range of UK policy analyses, research collaborations and academic publication from 2006 through 2009. Major outputs are listed below. As a deterministic model which focuses on scenario and sensitivity analysis to characterise uncertainty, each model run is carried out with a range of alternate model assumptions and model extensions. Therefore the underlying data listed here is based on the 2007 Energy White Paper analysis. It is stressed that successive model applications use alternate assumptions and this documentation should hence be viewed as a guide on model structure and not as a definitive data depiction.

Balta-Ozkan N., N. Strachan (2009), Hydrogen Systems Modelling, Chapter 8 in Hydrogen Energy: Economic and Social Challenges, (ed) P. Ekins, Earthscan
Strachan N., T. Foxon, and J. Fujino (2008), Modelling Long-Term Scenarios for Low Carbon Societies, Earthscan.