ETSAP seminar, Canberra, 28 May 2002

Top-Down and Bottom-Up Models: Bridging the Gap

Some MARKAL capabilities in Australian energy policy analysis:
mandated target for renewable electricity

Barry Naughten

ABARE Conference paper 2002.9

Structure of paper

Two parts:

1. guide to ABARE’s recent MARKAL-based policy analysis
   - highlighting 4 particular model features including recent ETSAP technical innovations and
   - focussing on some policy applications in greenhouse gas emissions abatement
     that differ from the optimal ‘carbon penalties’ approach—
     for example …

2. case study: mandated target for renewable electricity
**MARKAL: a quick outline**

- ‘MARKet Allocation’ model; developed by and for the IEA through ETSAP
- ‘bottom up’, ‘engineering’ model approach to (national) energy systems analysis:
  - purpose: ‘technology assessment’ / ‘policy analysis’ in an energy system-wide context;
  - simulates market behaviour over time: inter-temporal optimisation
    - minimising a discounted cost function with
    - numerous standard and any number of user-defined constraints

- Australian MARKAL:
  - regional structure with trade in natural gas and electricity among the six states (Stocks & Musgrove 1984)
  - ABARE’s development and use in policy analysis since 1991
MARKAL Reference Energy System’ (RES)

- **nodes** are **technologies** and **energy sources**
- connected by **flows of energy** (and potentially, **materials**)
- implies an accounting or **balancing** process
  - energy ‘comes from somewhere and goes somewhere’ … ‘is neither created nor destroyed’

- **RHS**: energy services (externally specified) patterns and levels
  - sums of the ‘useful energy’ outputs of competing end use technologies
  - recalling that MARKAL is a ‘demand driven’ model

- **LHS**: energy sources (or ‘resources’)
  - fossil fuel imports (less exports), extraction,
  - renewable resources;

- **centre**:
  - conversion (electricity supply);
  - processes (for example, oil refining, gas pipelines)

Part 1.

- 3 categories of **policy instrument** in analysis of greenhouse gas emissions abatement:
  1. ‘carbon penalties’
  2. ‘non-optimal’ policies;
  3. claimed ‘no regrets’ cases.

Comment:
- ‘category 1’ [for example, internationally tradable emission permits] is generally considered the **theoretically preferred** option and remains the **bench-mark** in comparing cost-effectiveness of policy instruments …
- but policy instruments of categories 2 & 3 are the focus of this paper.
- One (of several) motivations is to show that MARKAL has important **practical application** in **critique of policy instruments** (for example, presented by interest groups) that in some cases may thus be demonstrated to be **far from optimal or cost-effective**—even for achieving a policy objective that may be agreed.
In considering these categories of policy instrument, the focus will also be on

- ABARE’s use of four MARKAL technical model features due to ETSAP members:
  1. price elasticities of demand for energy services;
  2. taxes and subsidies on energy flows;
  3. technology-specific ‘hurdle rates’ of return on investment;
  4. easily applied sub-systemwide constraints.

Model feature 1:

**Price elasticities** of demand for energy services*

- addressing price-*inelasticity* of ‘energy services’ (*not* ‘final energy consumed’) in standard MARKAL

Applications to modelling: (ABARE 1995a)

1. greenhouse gas targets:
   - relatively imminent and stringent targets for abating emissions
   - large price-induced shocks depressing energy services levels;
   - however, stringent targets such as those analysed in the early 1990s are not now on the policy agenda over medium-term forecast periods

* Tosato (1980); Loulou & Lavigne (1997)
Model feature 1 (continued)

Price elasticities of demand for energy services

2. ‘rebound effect’ (ABARE 1995b):
   - exogenous energy efficiency improvement not only …
     \[ \rightarrow \downarrow \text{consumption energy} \quad \text{but also the ‘rebound’ i.e.} \]
     \[ \rightarrow \downarrow \text{unit cost} \rightarrow \uparrow \text{consptn. energy services} \rightarrow \uparrow \text{consptn. energy} \]
   - however if energy efficiency improvement is price-induced, rather than exogenous, then
     \[ \downarrow \text{unit cost} \text{ is moderated by higher unit cost of the more energy-efficient technologies compared with ‘standard’ technologies.} \]

Hence, after initial ‘elastic MARKAL’ studies in 1995, the inelasticity feature of standard MARKAL (with respect to energy services) has largely been judged an acceptable approximation in most policy analyses.

Model feature 2:

Higher ‘hurdle rates’ of return on investment in certain energy technologies

- higher hurdle rates $>\,$ default discount rate (8% real in Australian MARKAL)

Applications to modelling:
- liberalisation of electricity markets (ABARE 2000)
  - new electricity capacity entails greater investment risk now borne by owners /investors rather than consumers /tax-payers;
    - reflected in imposed higher technology-specific hurdle rates;
    - associated with new investment in technologies characterised by (e.g.) longer construction lead-times, with less ‘modularity’;
- investment in end-use energy conservation (ABARE 2002)
  - high required rates of return have been reported in numerous empirical studies
    - including those undertaken for ABARE.
Model feature 3:

Taxes and subsidies on energy flows

among key energy taxes internationally are taxes on transport fuels

Applications to modelling:

examples from publications (CNG, ABARE 1993) and work-in-progress (biofuels, ABARE 2002):

• ‘alternative’ transport fuels such as CNG, fuel ethanol blends and other biofuels:
  – generally excise-exempt
  – often also in receipt of other subsidies
to assess:
  – economic viability
  – cost-effectiveness in emissions abatement

Model feature 4:

Ability to apply a wide range of sub-systemwide constraints

• Such sub-system constraints are an original ‘design feature’ of MARKAL
  – but ease of application has recently been greatly improved with the current user-interface (ANSWER)

• illustrated in part 2 in which
  – a ‘lower bound’ constraint is imposed as a ‘mandated target’ for renewable electricity technologies

ABARE
Part 2*:
Mandated renewable electricity target policy

‘electricity retailers and other large electricity buyers will be legally required to source an additional 2 per cent of their electricity from renewable or specified waste-product energy sources by 2010 …’ (Prime Minister’s Statement, November 1997, emphasis added)

– cross-subsidy scheme …
– implemented through a system of tradable certificates
designed to

– achieve this target at least cost and
– provide a ‘level playing field’ among the defined eligible sources.

* based on Naughten & Noble (2001)

The approach adopted in the mandated renewable electricity target policy thus has some features of

• a market-based approach to reducing greenhouse gas emissions
  – that is, the use of tradable certificates

• a ‘command and control’ approach
  – in that it is based on a target different from minimising emissions, as such.
Mandated renewable electricity target: objectives

- ‘to accelerate the uptake of energy from renewable or specified waste product sources in grid-based applications, so as to reduce greenhouse gas emissions’;
- ‘as part of the broader strategic package, to stimulate renewables, provide an on-going base for the development of commercially competitive renewable energy’;
- ‘to contribute to the development of internationally competitive industries which could participate effectively in the burgeoning Asian energy market’

- as greenhouse gas emissions commitments become more widely applicable internationally c.f. ‘Porter thesis’.

Data: relative costs of renewable electricity technologies

- ‘levelised costs’ (calculated outside the model*) vary in a wide range, for example,
  - at lower limit, $A15–38 / MWh (for bagasse-based electricity), $A29–49 / MWh (for wind-power);
  - much higher costs $A130–200+/ MWh (crop waste and photo-voltaics);
- but, in addition to these relative unit costs, there are important upper bounds and other constraints that co-determine the role of each type of technology in a feasible least-cost outcome.

* but using the model database, from a consultancy (Redding and Associates 2000)
MARKAL-based analysis replicates operation of tradable certificates allocated to major electricity consumers to achieve:

• least cost configuration of the electricity / energy system;
• the designated annual GWh targets for renewable energy.

(Montgomery, D. 1972, J Econ Theory)

MARKAL-based analysis of renewable electricity increment indicates:

• timing;
• contributions from each eligible type;
• additional cost to the energy system;
• aggregate reduction in CO₂ emissions

Figure 1:

– total level of electricity output from eligible renewable technologies in the reference case;
– the additional such output brought about by the target.
Results from the MARKAL analysis:

Total output from eligible renewable electricity technologies

- **key finding**: .... an effect of the mandated target is to bring forward the adoption time of these new and renewable technologies
  - that is, in the absence of the mandated target, a not dissimilar level of the technologies would have been adopted—but with a delay of 10–20 years.
Fig. 4 Increment to ‘eligible’ renewables under 2 per cent target policy relative to underlying growth in Reference case: MARKAL analysis.

Contributions to total renewables: ‘reference case’ versus ‘mandated target case’

<table>
<thead>
<tr>
<th></th>
<th>Reference case</th>
<th>Mandated target</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2000</td>
<td>2010</td>
</tr>
<tr>
<td>Bagasse — sugar mills</td>
<td>4.6</td>
<td>3.9</td>
</tr>
<tr>
<td>Hydro and pumped storage</td>
<td>90.8</td>
<td>88.1</td>
</tr>
<tr>
<td>Wind</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>Biomass co-firing</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>‘Municipal’ biomass</td>
<td>3.1</td>
<td>4.3</td>
</tr>
<tr>
<td>Forestry residues and wood waste</td>
<td>0.8</td>
<td>3.0</td>
</tr>
<tr>
<td>Other</td>
<td>0.3</td>
<td>0.4</td>
</tr>
</tbody>
</table>
Mandated renewables target policy: cost and emissions abatement

• **total net cost** of mandated renewables target policy:
  
  $2000 \text{ A0.75 billion discounted back to 2000 at 8 per cent real}$

• decline in **cumulative** energy sector CO$_2$ emissions:
  
  $0.7\%$ over whole period 2000-30

---

Analysis of ‘non-optimal’ and ‘no regrets’ abatement policies

<table>
<thead>
<tr>
<th>examples of policies and policy settings</th>
<th>... other than direct penalties on greenhouse gas emissions:</th>
<th>claimed ‘no regrets’ reduction of greenhouse gas emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td>mandated renewable electricity target</td>
<td>‘non-optimal’ policies or adverse emissions effects</td>
<td>where other objectives exist: e.g., improving international competitiveness of renewables</td>
</tr>
<tr>
<td></td>
<td>e.g. non-neutral or ‘portfolio’ approaches unduly favouring high unit cost renewable technologies</td>
<td></td>
</tr>
<tr>
<td>energy efficiency programmes</td>
<td>arbitrary regulation, (e.g., broad premature scrapping of less energy-efficient technologies)</td>
<td>efficiently correcting imperfect information, principal-agent conflicts; taking account of higher hurdle rates</td>
</tr>
<tr>
<td>energy taxes and subsidies</td>
<td>introducing new ‘distorting’ taxes and subsidies without a valid ‘externalities’ basis</td>
<td>removal of ‘market distorting’ taxes and subsidies; new ‘pigovian’ taxes for non-greenhouse emission or other externalities</td>
</tr>
<tr>
<td>liberalising energy markets</td>
<td>prolonging life-times of existing carbon-intensive assets (e.g., refurbishment of coal-fired electricity generation)</td>
<td>where modular, short lead-time, decentralised technologies (with lower hurdle rates) are also less greenhouse gas intensive (e.g., CCGTs)</td>
</tr>
</tbody>
</table>
Conclusion

The paper

1. notes that actual or proposed policies and practices influencing greenhouse gas emissions:
   – often differ from the ‘theoretically preferred’ carbon penalties;

2. notes that analysis of these issues requires detailed and reliable specification of technologies in a sufficiently broad ‘efficient markets’ context.

and …

Conclusion (continued)

3. claims that in regard to MARKAL’s use in modelling greenhouse gas emissions abatement …

   – as well as modelling effects of the theoretically preferred carbon penalties—which remain the ‘economic efficiency bench-mark’ …

   – MARKAL is also well-suited to critical analysis of ‘non-optimal’ and/or claimed ‘no regrets’ cases …

   – as illustrated by ABARE’s MARKAL-based published and on-going research to date.

Thank you.
—may have *joint objectives other than or in addition to* greenhouse gas emissions abatement—for example, policies

- encouraging an industry with export potential e.g. certain renewable electricity technologies;
- liberalising energy markets;
- reducing (non-greenhouse) emissions or externalities;
- reducing long term dependence on certain energy imports
  —if or where this is a national policy goal
Eligible renewable energy sources

- solar (grid-linked photovoltaics, steam generating solar thermal capacity);
- wind;
- ocean, wave and tidal;
- hydro;
- geothermal;
- biofuels (landfill gas, biogas, biomass);
- specified waste;
- solar water heating;
- pumped storage hydro;
- Renewable Stand Alone Power Supply (RAPS) systems;
- co-firing renewables with fossil fuels; and
- fuel cells using a renewable fuel.

Table 1a. Eligible renewable electricity technologies: pre tax capital costs and unit costs, 2010: lower cost technologies

<table>
<thead>
<tr>
<th>Technology</th>
<th>Capital cost</th>
<th>Availability factor</th>
<th>Averaged unit cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>bagasse, existing (sunk costs)</td>
<td></td>
<td>0.15</td>
<td>15</td>
</tr>
<tr>
<td>bagasse + waste, new</td>
<td>1500</td>
<td>0.40–0.80</td>
<td>28–38</td>
</tr>
<tr>
<td>wind power</td>
<td>1400</td>
<td>0.25–0.40</td>
<td>29–49</td>
</tr>
<tr>
<td>small hydro</td>
<td>2300</td>
<td>0.45</td>
<td>48</td>
</tr>
<tr>
<td>biomass into coal capacity</td>
<td>380</td>
<td>0.90</td>
<td>23</td>
</tr>
<tr>
<td>‘municipal’ a</td>
<td>2400-3000</td>
<td>0.85–0.90</td>
<td>24–38</td>
</tr>
<tr>
<td>wood waste, forestry residues</td>
<td>3000</td>
<td>0.85</td>
<td>60</td>
</tr>
</tbody>
</table>

*a includes landfill gas, solid waste, waste water and wet waste*
Table 1b Eligible renewable electricity technologies: pre tax capital costs and unit costs, 2010: **higher cost technologies**

<table>
<thead>
<tr>
<th>Technology</th>
<th>capital cost/€kW</th>
<th>availability factor</th>
<th>averaged unit cost/€/MWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>black liquor</td>
<td>2500</td>
<td>0.20</td>
<td>124</td>
</tr>
<tr>
<td>PV grid connected</td>
<td>4500</td>
<td>0.18</td>
<td>209</td>
</tr>
<tr>
<td>PV RAPS</td>
<td>5300</td>
<td>0.22</td>
<td>200</td>
</tr>
<tr>
<td>solar thermal</td>
<td>2100</td>
<td>0.22</td>
<td>88</td>
</tr>
<tr>
<td>energy crops</td>
<td>2800</td>
<td>0.50</td>
<td>88</td>
</tr>
<tr>
<td>crop waste</td>
<td>2880</td>
<td>0.50</td>
<td>127</td>
</tr>
</tbody>
</table>

**Results from the MARKAL analysis:**

Total output from eligible renewable electricity technologies

- **Figure 2:**
  
  difference in:
  
  – the level of new and renewable output measured *vs* the Reference case level over the projection period.
  
  – the output increase over time measured against the level at the beginning of the projection period (Reference case, sub-period 2000).
Defining the target

Table 1: Required additional renewables based electricity generation under mandated target Bill

<table>
<thead>
<tr>
<th>Year</th>
<th>2000</th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010-2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>GWh</td>
<td>0</td>
<td>400</td>
<td>1100</td>
<td>1800</td>
<td>2600</td>
<td>3400</td>
<td>4500</td>
<td>5600</td>
<td>6800</td>
<td>7826</td>
<td>8884</td>
</tr>
</tbody>
</table>

a implying a reduction corresponding to savings in fossil-fuelled electricity due to projected use of solar-boosted water heaters of 274 GWh (in 2009) and 616 GWh (in 2010) according to calculations supplied to ABARE by McLennan-Magasanic.
Figure 3. Post-2000 increment to 'eligible' renewables under 2 per cent target policy: MARKAL analysis

Table 2. Penalty of $40 / MWh under mandated target legislation: possible interpretations of cost to major electricity consumers (2000$ / MWh)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>a. tax deductible, indexed</td>
<td>40.00</td>
<td>40.00</td>
<td>40.00</td>
<td>40.00</td>
<td>40.00</td>
</tr>
<tr>
<td>b. tax deductible, not indexed</td>
<td>40.00</td>
<td>34.50</td>
<td>29.76</td>
<td>25.67</td>
<td>22.15</td>
</tr>
<tr>
<td>c. not tax deductible, indexed</td>
<td>57.00</td>
<td>57.00</td>
<td>57.00</td>
<td>57.00</td>
<td>57.00</td>
</tr>
<tr>
<td>d. not tax deductible, not indexed</td>
<td>57.00</td>
<td>49.17</td>
<td>42.41</td>
<td>36.59</td>
<td>31.56</td>
</tr>
</tbody>
</table>

$40 / MWh penalty for non-compliance
### Table 4. Effect of mandated target in sub-period 2010: results from Australian MARKAL analysis: shares

<table>
<thead>
<tr>
<th></th>
<th>Reference case</th>
<th>Mandated target</th>
<th>Differences rel. to case period 2000</th>
<th>%</th>
<th>%</th>
<th>%</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bagasse - sugar mills</td>
<td>4</td>
<td>13</td>
<td>39</td>
<td>33</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydro including pumped storage</td>
<td>88</td>
<td>68</td>
<td>10</td>
<td>13</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wind</td>
<td>0</td>
<td>4</td>
<td>17</td>
<td>15</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biomass co-firing</td>
<td>0</td>
<td>3</td>
<td>11</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>'Municipal' biomass (various)</td>
<td>4</td>
<td>9</td>
<td>23</td>
<td>23</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forestry residues and wood waste</td>
<td>3</td>
<td>2</td>
<td>0</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100</strong></td>
<td><strong>100</strong></td>
<td><strong>100</strong></td>
<td><strong>100</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*a period 2010 in MARKAL is the average of 2008-2012 hence the target averaged over this period is slightly less than that for the year 2010, that is, 8884 GWh. It includes wet waste, landfill gas, MSW combustion and municipal waste-water.

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**Equivalent annual costs**

- far from uniform over time
- peak in the sub-period ‘2010’ (that is, 2008-12) at an undiscounted value of $319 million
- but in later periods are negative (reflecting consequently reduced costs of fossil fuels)
Components of total system discounted cost of meeting mandated target

<table>
<thead>
<tr>
<th></th>
<th>2000$m</th>
</tr>
</thead>
<tbody>
<tr>
<td>domestic fuel costs</td>
<td>-1096</td>
</tr>
<tr>
<td>investment in supply</td>
<td>1440</td>
</tr>
<tr>
<td>other</td>
<td>405</td>
</tr>
<tr>
<td>total costs</td>
<td>749</td>
</tr>
</tbody>
</table>

CO$_2$ emissions reduction due to mandated target

reduction in CO$_2$ emissions relative to Reference case:
- ‘2010’: 1.6 %:
  - ‘2015’: 1.8 %;
  - ‘2020’: 1.3 %
  - declining to 0.3 % by 2025
Departures from the ‘least cost’ principle: the ‘portfolio’ approach

- wind power (a moderate cost technology)
- grid-connected PV cells (a very high cost but projected to fall over time)

share of the mandated target incremental output from these technologies by 2010 and subsequently forced to 30% (wind) and 10% (PV cells)
Departure from the least cost / ‘level playing field’: the ‘Portfolio approach’

either:

- guarantee at least a given share of additional generation to a particular favoured type of renewable source (for example, wind, PVs)  

or

- seek to limit shares available to less favoured technologies (for example, native forests waste).

Departures from the ‘least cost’ principle: the ‘portfolio’ approach

<table>
<thead>
<tr>
<th>scenario</th>
<th>2000$ million</th>
<th>factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>‘least cost’</td>
<td>749</td>
<td>1.0</td>
</tr>
<tr>
<td>‘portfolio’ approaches:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- wind share a</td>
<td>975</td>
<td>1.3</td>
</tr>
<tr>
<td>- photovoltaic share b</td>
<td>2649</td>
<td>3.5</td>
</tr>
</tbody>
</table>

a required to reach 30 per cent of the mandated target increment by 2010.

b required to be 10 per cent by 2010, maintained until 2020.
MARKAL: history

- **MARKet ALlocation model**
- developed by and for the IEA
  - in the early 1980s to model technology assessment in a context of high and rising oil prices
  - modelling tool still in active development under IEA auspices
- remains widely used to assess technologies in
  - greenhouse gas emissions abatement
  - micro-economic reform
- **Australian MARKAL:**
  - regional structure with trade in natural gas and electricity among the six states (Stocks & Musgove 1984)
  - ABARE’s development and use since 1991

What data does MARKAL use?

‘bottom up’, engineering-economic model requiring detail on:

- **base period energy flows** (inputs, outputs and capacities of technologies)
- individual **energy technologies and resources** available to the energy system both in the base period and prospectively
  - engineering data (e.g., availabilities, energy efficiencies, base period activities and capacities);
  - economic data (e.g., investment costs, operating costs, delivery costs);
  - environmental data (e.g., greenhouse gas emission coefficients associated with each energy resource or combustion technology).
MARKAL’s key attributes

• ‘Engineering-economic’ representation of an entire energy system usually at the national level
  – but can also be at the locality or supranational level
  – sub-national ‘regional analysis’: incorporating multi-electric grid and sub-national regional trade in energy carriers

• intertemporal optimisation (for example, least cost solution) subject to user-defined constraints including
  – meeting externally projected consumption of energy services
  – environmental standards and targets
  – commitments and policies (for example, 2% renewables target)
  – saturation effects
  – market distortions

• simulating market behaviour
  – but with ‘perfect foresight’

Updated MARKAL database: characterisation of CCGTs and competing technologies

• Description of the electricity sector data and the update process (consultants: SKM and REM)

• Technical progress

• Capital versus energy efficiency trade-off

• Modularity in investment

• Flexibility in operation
Model results and discussion

- Effect of existing CCGT capacity commitments
  - Queensland (260 MW Mica Ck)
  - South Australia (487 MW Pelican Pt.)
- Input prices for natural gas relative to coal
  - recent downward trends in coal prices
    - mine restructuring, Western Australia and South Australia
    - NSW, Queensland and Victoria
  - future trends in natural gas prices?
    - 3 scenarios to probe effects of micro-economic reform in gas markets
- Refurbishing existing coal-fired capacity
- Higher required rates of return on electricity capacity investment
- Cost-cutting productivity improvement in CCGT manufacture

MARKAL Scenarios analysed

two principal scenarios were simulated under least cost assumptions:

- a ‘Reference case’ with no target imposed on additional renewables-based electricity output;
- a ‘mandated target’ case consistent with table 1.