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

Some MARKAL capabilities in Australian energy policy analysis:

mandated target for renewable electricity

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ABARE Conference paper 2002.9

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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

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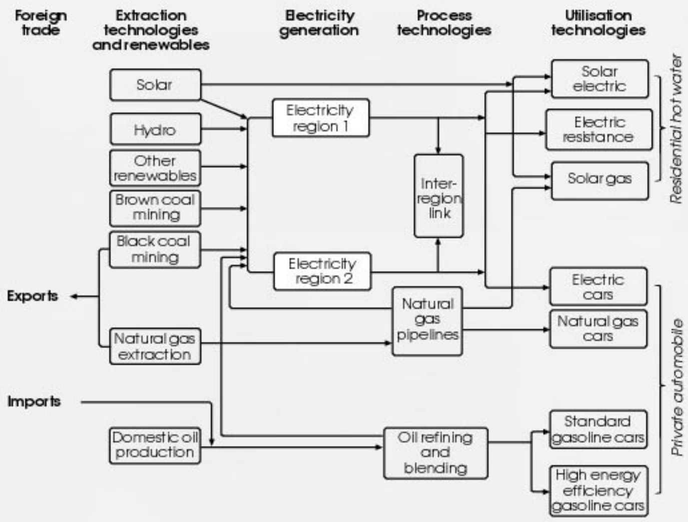
MARKAL: a quick outline

- ‘***MARK***et ***Al***location’ 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

Schematic representation of energy system in Australian MARKAL



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 now 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)

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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.

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Part 1. (continued)

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**.

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Model feature 1:

Price elasticities of demand for energy services*

- addressing price-***in***elasticity 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)

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Model feature 1 (continued)

Price elasticities of demand for energy services

2. 'rebound effect' (ABARE 1995b):

– exogenous energy efficiency improvement ***not only …***

→ ↓ consumption energy ***but also the 'rebound'* i.e.**

→ ↓ unit cost → ↑ consptn. energy services → ↑ consptn. energy

– however if energy efficiency improvement is price-induced, rather than exogenous, then

↓ unit cost 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.

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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.

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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

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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

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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.

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* based on Naughten & Noble (2001)

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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.

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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’.

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Data: relative costs of renewable electricity technologies

- ‘levelised costs’ (calculated outside the model*) vary in a wide range, for example,
  - at lower limit, $A**15–38** / MWh (for **bagasse-based** electricity), $A**29–49** / MWh (for **wind-power**);
  - much higher costs $A**130–200+** / 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)

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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*)

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MARKAL-based analysis of renewable electricity increment indicates:

- timing;
- contributions from each eligible type;
- additional cost to the energy system;
- aggregate reduction in CO_2 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.

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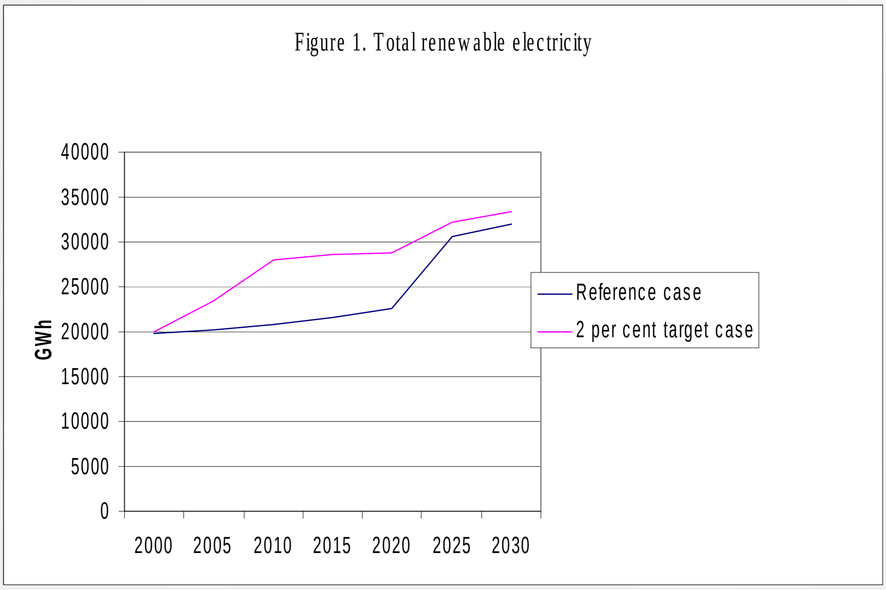

Results from the MARKAL analysis:

Total output from eligible renewable electricity technologies

- **key finding**: …. an effect of the mandated target is to <u>bring forward</u> 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.

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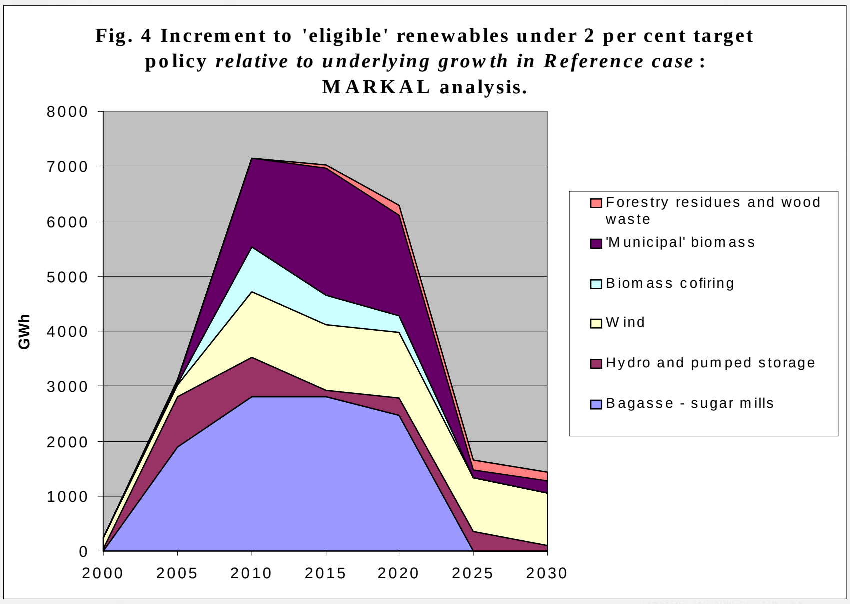

Contributions to total renewables: ‘reference case’ *versus* ‘mandated target case’

	Reference case		Mandated target
	2000	2010	2010
Bagasse —sugar mills	4.6	3.9	12.9
Hydro and pumped storage	90.8	88.1	68.2
Wind	0.3	0.3	4.5
Biomass co-firing	0.0	0.0	2.9
‘Municipal’ biomass	3.1	4.3	9.0
Forestry residues and wood waste	0.8	3.0	2.2
Other	0.3	0.4	0.3

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Mandated renewables target policy: cost and emissions abatement

- ***total net cost*** of mandated renewables target policy:

  2000$A **0.75 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

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Analysis of 'non-optimal' and 'no regrets' abatement policies

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

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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 …

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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.

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–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

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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.

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

Technology	capital cost	availability factor	averaged unit cost
	$/kW		$ / MWh
bagasse, existing	(sunk costs)	0.15	15
bagasse + waste, new	1500	0.40–0.80	28–38
wind power	1400	0.25–0.40	29–49
small hydro	2300	0.45	48
biomass into coal capacity	380	0.90	23
‘municipal’ a	2400-3000	0.85–0.90	24–38
wood waste, forestry residues	3000	0.85	60

a includes landfill gas, solid waste, waste water and wet waste

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Table 1b Eligible renewable electricity technologies: pre tax capital costs and unit costs, 2010: **higher cost technologies**

Technology	capital cost $/kW	availability factor	averaged unit cost $ / MWh
black liquor	2500	0.20	124
PV grid connected	4500	0.18	209
PV RAPS	5300	0.22	200
solar thermal	2100	0.22	88
energy crops	2800	0.50	88
crop waste	2880	0.50	127

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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).

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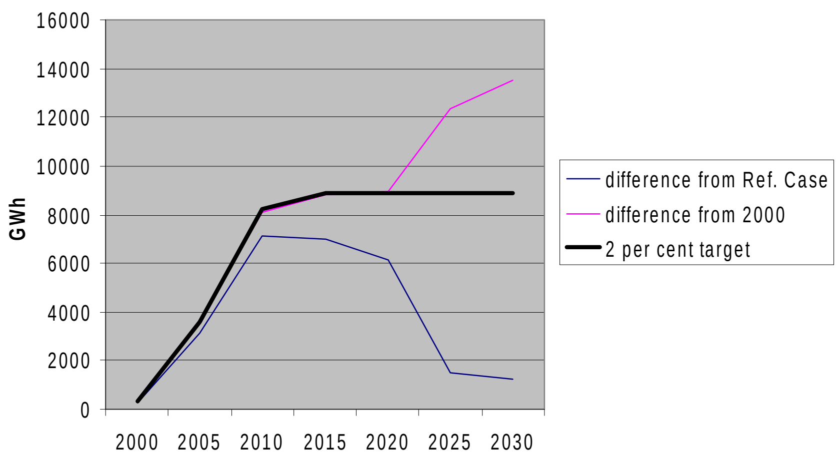
Figure 2. Addition to Renewables due to target



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Defining the target

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

year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009 **a**	2010-20 **a**
GWh	0	400	1100	1800	2600	3400	4500	5600	6800	7826	8884
PJ	0	1.44	3.96	6.48	9.36	12.24	16.2	20.16	24.48	28.17	31.98

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.

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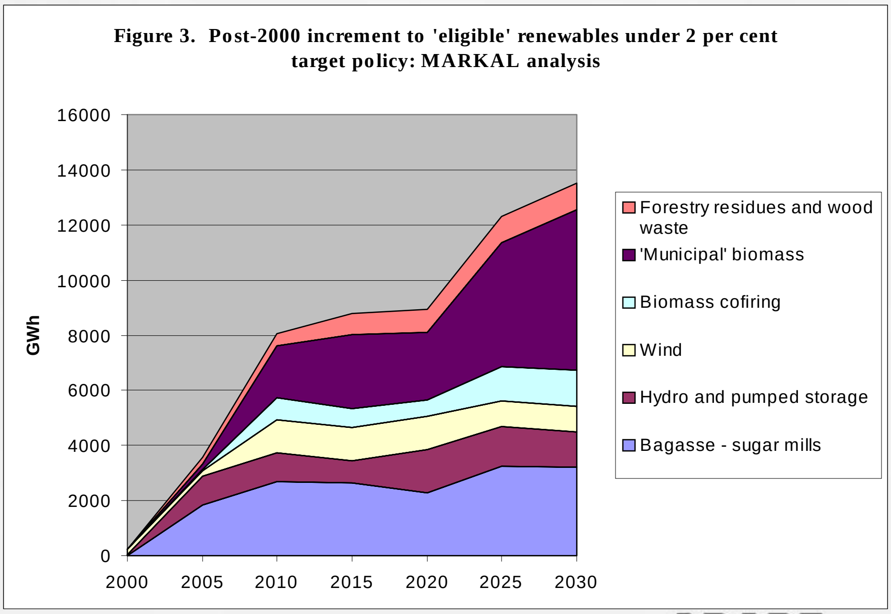

$ 40 / MWh penalty for non-compliance

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

Assuming penalty is:	2000	2005	2010	2015	2020
a. tax deductible, indexed	40.00	40.00	40.00	40.00	40.00
b. tax deductible, not indexed	40.00	34.50	29.76	25.67	22.15
c. not tax deductible, indexed	57.00	57.00	57.00	57.00	57.00
d. not tax deductible, not indexed	57.00	49.17	42.41	36.59	31.56

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Table 4. Effect of mandated target in sub-period 2010 a: results from Australian MARKAL analysis: shares

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

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. **b** 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)

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Components of total system discounted cost of meeting mandated target

	2000$m
domestic fuel costs	-1096
investment in supply	1440
other	405
total costs	749

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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

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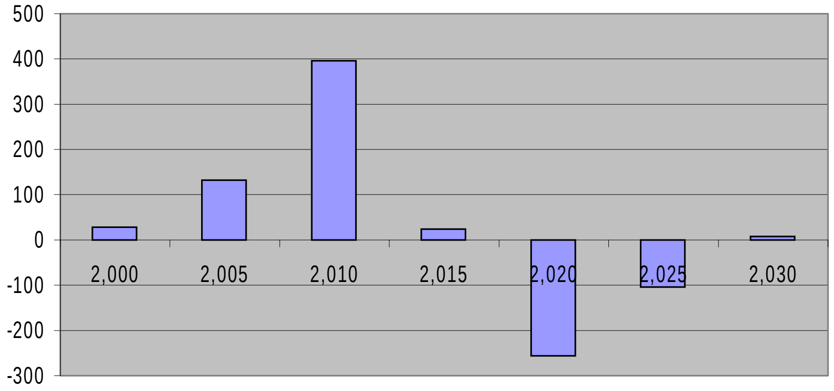
Fig. 2 Annual increase in investment in supply due to application of Mandated target (averaged over five-yearly periods: 2000$m)



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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)

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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).

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

scenario	2000$ million	factor
‘least cost’	749	1.0
‘portfolio’ approaches:		
- wind share [a]	975	1.3
- photovoltaic share [b]	2649	3.5

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.

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MARKAL: history

- ***MARK***et ***AL***location 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

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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).

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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'

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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

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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

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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.

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