Some MARKAL capabilities in Australian energy policy analysis and modeling the mandated target for renewable electricity in Australian MARKAL

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Referring to recent ABARE published research, this paper notes the use of several features of enhanced MARKAL to improve the model’s representation of ‘real world’ markets, with applications in policy analysis. Relating to policies to abate carbon dioxide emissions, these enhancements include two types of approach other than the generally recognised approach that involves carbon penalties of some kind (notably, internationally tradable emissions permits). The first approach may involve higher cost, for example, through introduction of new market distortions, while the second may involve coincident removal of such distortions.

The second part of the paper illustratively presents one particular case: modeling the Australian government’s mandated target for renewable electricity. This MARKAL based analysis simulates achievement of this target at least cost — the objective of the program’s use of a system of tradable certificates. The analysis indicates the contributions from eligible technologies, the consequent additional resource cost and the associated reduction in carbon dioxide emissions from the national energy system.
Introduction
As an intertemporal linear programming model, MARKAL represents market behavior, including the operation of markets over time and the process of investment in physical assets. In this respect, it resembles dynamic (or long run) general equilibrium models. However, unlike most general equilibrium models, MARKAL models also represent salient features of actual technologies, in this case those involved in energy extraction, conversion, processing and use.

This paper is in two parts, based on recent MARKAL based research in ABARE using the regionalised Australian database.

The first part of this paper includes references to ABARE papers analysing two types of approach that are distinct from a ‘least cost carbon penalties’ option. These two approaches are:

- ‘nonoptimal’ approaches — policy approaches and instruments that, under some circumstances, may entail higher costs through introducing new market distortions; and
- claimed ‘no regrets’ approaches — those claimed to abate greenhouse gas emissions while at the same time either removing existing market distortions or internalising other, nongreenhouse, externalities

The approaches in this part of the paper rely partly on improvements to MARKAL introduced over the past decade. Such improvements include the ability to readily specify:

- price elasticities of demand for energy services;
- taxes and subsidies on energy flows;
- technology specific ‘hurdle rates’ — that is, required rates of return on investment.

The main policy objective underlying the topics reviewed in this paper is the abatement of greenhouse gas emissions. The policy instruments generally considered are based on carbon penalties at rates suitably chosen to obtain particular desired least cost outcomes. Ultimately, national emission targets might be achieved (for example) through a market for internationally tradable emission permits. That market would set the required rate of penalty not only in the energy sector but economywide and for all eligible greenhouse gases.

The second part of the paper illustrates MARKAL analysis of one policy recently implemented in Australia — the mandated target for renewable electricity.
Background to ‘standard MARKAL’ and the Australian regionalised database

The MARKAL (MARKet ALlocation) model was developed under the auspices of the International Energy Agency (Fishbone and Abilock 1981) and its development is still coordinated through an IEA Annex (Energy Technology Systems Analysis Project — ETSAP 2001). An overview of MARKAL model developments over two decades is provided on the ETSAP website (Seebregts, Goldstein and Smekens 2001).

MARKAL involves an intertemporal, linear programming approach adapted to the major features of national energy systems. Its data structure, or Reference Energy System, is illustrated schematically in figure 1. There are four blocks of technologies:

1. energy imports and resources, such as coal mines and gas extraction;
2. electricity generation and transmission;
3. other process technologies, including oil refining and various forms of energy transport — for example, gas pipelines; and

Figure 1: Schematic representation of energy system in Australian MARKAL

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**Foreign trade**
- Solar
- Hydro
- Other renewables
- Brown coal mining
- Black coal mining
- Natural gas extraction

**Extraction technologies and renewables**
- Natural gas pipelines
- Oil refining and blending

**Electricity generation**
- Electricity region 1
- Electricity region 2

**Process technologies**
- Interregion link

**Utilisation technologies**
- Solar electric
- Electric resistance
- Solar gas
- Electric cars
- Natural gas cars
- Standard gasoline cars
- High energy efficiency gasoline cars

**Exports**
- Domestic oil production

**Imports**
- Residential hot water

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3
(4) utilisation technologies competing to meet the levels of consumption of energy services
(‘energy services’ are the outputs of ‘demand devices’: for example, billion kilometres a year of road passenger transport provided by various sorts of cars and buses represented in the database; lighting; space heating; air conditioning etc.) The forecasts of energy services are exogenously given and hence the model is described as ‘demand driven’.

The nodes in this ‘reference energy system’ (generally ‘technologies’) are connected by flows of ‘energy carriers’ — a generic term including primary energy forms and secondary energy forms such as electricity.

In the standard version of MARKAL used in this analysis, markets are simulated by minimising an objective function incorporating the costs of energy technologies and resources. The cost related parameters for each technology include unit investment costs (for example, $/kW), constant and variable operation and maintenance costs, and fuel delivery costs. Decision variables include capacity (GW or PJa), activity (PJ output which, for electricity, is defined for separate seasonal and diurnal periods). There are many other specific parameters, including emission coefficients (for example, carbon dioxide emissions per unit output) for each technology.

The objective function to be minimised is discounted over time at a rate chosen by the user and, for Australian MARKAL, this has been a value of 8 per cent in real terms. The process modeled has been described as representing an assumption of ‘perfect foresight’ in the sense that actions, such as investment decisions, taken early in the period are determined simultaneously, with later systemwide consequences.

A feature of Australian MARKAL has been its regional structure corresponding to the six states (Stocks and Musgrove 1984). The Australian MARKAL database was thus the first to incorporate a regional treatment of electricity (generation, consumption and interregional transmission) and natural gas (sources, pipelines and consumption).

Enhanced features of MARKAL
Table 1 lists selected MARKAL model enhancements from recent years and some examples of MARKAL based research undertaken in ABARE that have used these features. These enhancements are reviewed before going on to consider the case studies.

Price elastic demand for energy services
By providing some background on price elastic demand for energy services in Australian MARKAL, some reasons are given to justify abstracting from this aspect in most of the case studies referenced in this paper. That is, demand for energy services is generally
treated as inelastic. Reasons for this are given in appendix A in which two cases are considered: first, the imposition of an energy systemwide target for carbon dioxide emissions and, second, the use of policies to enhance end use energy efficiency. In this second case, elastic MARKAL was used to assess the size of a ‘rebound effect’.

### Technology specific hurdle rates of return: modeling investment in competitive markets

Standard MARKAL already offers representation of key aspects of intertemporal markets in the investment process, for example:

- **MARKAL** has scope for specifying capacity levels of assets in place at the beginning of the period of analysis (now typically the beginning of subperiod, ‘2000’). Since costs associated with existing assets are sunk, this specification is a major determinant of investment patterns and requirements, especially in the earlier part of the projection period (now 2000–35). The case of coal fired electricity generation in eastern Australian is illustrative — such sunk capacity is of relatively recent vintage, reflecting the 1980s investment boom. This feature of sunk capacity together with technological and market developments favoring longer asset lives and improved capacity utilisation will preclude for some time to come any ‘dash for gas’ in base load electricity generation (see further discussion below).

- The pattern of physical depreciation of assets over their user specified lifetimes is taken into account in MARKAL. This includes the possibility of refurbishment as an alternative to replacement of assets — for example, the case of refurbished coal fired electricity capacity as an alternative to investment in new assets to be discussed below (Naughten 2000).

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### Table 1: Some recent MARKAL enhancements with applications to policy analysis

<table>
<thead>
<tr>
<th>MARKAL enhanced feature</th>
<th>Application to policy analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price elasticities of demand for energy services</td>
<td>Potentially important where there are either:</td>
</tr>
<tr>
<td></td>
<td>• price induced shocks to energy services that are significant, as with relatively stringent greenhouse gas emissions abatement targets</td>
</tr>
<tr>
<td></td>
<td>• ‘rebound effects’ consequent on exogenous energy efficiency improvement</td>
</tr>
<tr>
<td>Technology specific ‘hurdle rates’ of return on investment</td>
<td>• differential hurdle rates in electricity supply depending on lead times, modularity etc of different generation technologies</td>
</tr>
<tr>
<td></td>
<td>• relatively high required rates of return on investment in end use energy conservation as reported in numerous empirical studies</td>
</tr>
<tr>
<td>Taxes and subsidies on energy flows</td>
<td>• economic viability of fuel ethanol blends and cost effectiveness in abatement of greenhouse gas emissions</td>
</tr>
</tbody>
</table>
• Changing (typically declining) rates of capacity utilisation over the life time of certain (dated) assets are also possible in MARKAL — for example, for motor cars (Naughten, Bowen and Beck 1993). This feature is to be more routinely available in MARKAL’s successor TIMES (The Integrated MARKAL-EFOM System). The case treated in earlier analysis using Australian MARKAL was that of the representative motor car technology. In Australia, their utilisation was specified as declining from a factor of 1.2 in the first five years of life to 0.4 in the fourth and final five year period (15–20 years).

Considering ‘sunk costs’, for example, there is still a significant ‘capacity overhang’ in base load electricity capacity following the aborted investment boom of the 1980s — at least in New South Wales, although shortages of peak load capacity have been evident in other states. Given this capacity overhang, together with substantially longer plant life times and improved availabilities (discussed below), the ‘lock in’ influence of history — or ‘path dependence’ (Arthur 1989) — is evident and to a degree can be reflected in the model.

The use of technology specific ‘hurdle’ rates of return adds realism to the model’s treatment of the investment process in a competitive context. (This development is understood to be primarily due to Tom Kram, ECN, Petten, the Netherlands — Gary Goldstein 2002, personal communication) The modern economic theory of investment indicates that higher hurdle rates can be used to reflect uncertainty, irreversibility or sunk costs (that is, the profile of existing assets), and the benefits of ‘waiting’ or the rational deferral of investment. The theoretical basis for the use of such hurdle rates is in Dixit (1992), Pindyck (1991), Hassett and Metcalfe (1993, 1996) and Johnson (1994). This enhancement can be seen as one approach to overcoming (standard) MARKAL’s simplifying ‘ideal’ assumption of perfect foresight, masking an important aspect of risk in ‘real world’ markets.

Hurdle rates have found important applications in two of ABARE’s recent research projects using MARKAL, with the Australian database recently revised with respect to the electricity generation and commercial end use sectors respectively (Naughten 2000, 2002; Sinclair Knight Merz 2000; EMET 2002).

The former case is an example of a ‘no regrets’ claim, namely that liberalisation of electricity markets during the 1990s may abate greenhouse gas emissions while at the same time introducing cost saving economic efficiency improvements. The second case is more problematic in this regard but enables an improved approach to modeling the effect of end use energy efficiency enhancements in abating carbon dioxide emissions. Such energy efficiency enhancements can be in the context of:

• carbon penalties,
• existing or proposed energy efficiency programs, or
• taxes or subsidies on energy.
In the latter two cases, either the introduction or removal of costly market distortions may be involved in conjunction with the emission reductions.

**Taxes and subsidies on energy flows**

It is now readily possible in MARKAL to specify taxes or subsidies applicable to energy carriers. (This development is understood to be primarily due to Denise van Regemorter, Centre of Economic Studies, Catholic University of Leuven — Gary Goldstein 2002, personal communication) The objective cost function that is minimised thus includes costs *inclusive* of taxes and subsidies but the total discounted cost that is routinely *reported* nets off these revenue flows and therefore includes only true resource costs. Thus, market behavior as represented by the model’s optimisation process takes full account of taxes and subsidies but the main welfare indicator in standard MARKAL (the difference between the total discounted system cost in the test case and that in the reference case) appropriately *excludes* these financial transfers. This is important given that the span of the model is the energy sector only, unlike a national level GE model that can internalise such revenue transfers. The same treatment is also applicable in MARKAL to taxes on emissions if these exist in the database specification.

This feature is particularly important in analysis of the economics of alternative and biofuels in MARKAL, including with respect to an objective of greenhouse gas emissions abatement (Holmes and Naughten 1993; Naughten 2001). This is so, given that these fuels (in Australia and many other countries) are exempt or partially exempt from transport fuel

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**Table 2: Modeling ‘nonoptimal’ and claimed ‘no regrets’ policies abating greenhouse gas emissions**

<table>
<thead>
<tr>
<th>Examples of policies and policy settings</th>
<th>… other than direct penalties on greenhouse gas emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Nonoptimal policies or adverse effects</strong></td>
<td><strong>Claimed ‘no regrets’ policies</strong></td>
</tr>
<tr>
<td>Renewable electricity target</td>
<td>Non-neutral or ‘portfolio’ approaches favoring high unit cost technologies</td>
</tr>
<tr>
<td></td>
<td>Where other objectives exist — for example, improving international competitiveness of renewable electricity technologies</td>
</tr>
<tr>
<td>Energy efficiency programs</td>
<td>Arbitrary regulation — for example, broad premature scrapping of less energy efficient technologies</td>
</tr>
<tr>
<td></td>
<td>Cost effective correction of imperfect information, principal–agent conflicts</td>
</tr>
<tr>
<td>Taxes and subsidies</td>
<td>Introducing new ‘distorting’ taxes and subsidies without an ‘externalities’ basis</td>
</tr>
<tr>
<td></td>
<td>Removal of ‘market distorting’ taxes and subsidies; introducing ‘pigovian’ taxes for nongreenhouse emission or other externalities</td>
</tr>
<tr>
<td>Liberalising reform of energy markets</td>
<td>Prolonging life times of existing carbon intensive assets – for example, refurbishing coal fired generation</td>
</tr>
<tr>
<td></td>
<td>Where modular, short lead time, decentralised technologies are also less greenhouse gas intensive — for example, CCGTs</td>
</tr>
</tbody>
</table>
excise, and may also be subsidised directly. Again, the removal or introduction of taxes or subsidies may result in either the removal or introduction of market distortions, with consequent impacts on the cost of abatement.

Use of Australian MARKAL in modeling ‘nonoptimal’ and claimed no regrets cases in abatement of greenhouse gas emissions

Table 2 summarises and exemplifies such cases and is a compact guide to ABARE’s research in these areas.

The second section of this paper, drawing on Naughten and Noble (2001), will present the essentials of MARKAL analysis of a mandated target for renewable electricity technologies.

Meeting the mandated renewable electricity target

Legislation implementing the government’s mandated renewable electricity target was approved by the Parliament on 8 December 2000. Under the 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 of Australia 1997) [emphasis added]

The Australian Greenhouse Office (AGO 2000) notes that the policy has three specific 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 ongoing base for the development of commercially competitive renewable energy; and

• to contribute to the development of internationally competitive industries which could participate effectively in the burgeoning Asian energy market.

Beginning in April 2001, the mandated target is to be implemented through a system of tradable certificates. The use of market mechanisms is aimed at achieving the target at least cost by providing a ‘level playing field’ among the eligible sources of renewable electricity. Operation of the scheme will be subject to a review in 2003. Up to date background information on the policy and proposed administrative arrangements can be found at AGO’s web site (www.ago.gov.au).
This paper provides an analysis of the policy measure based on the Australian MARKAL model — a ‘bottom up’ model of Australian energy production and consumption. The modeling provides projections for:

- expected contributions from eligible renewable technologies;
- the additional cost to the energy system from implementing the policy; and
- the reduction in carbon dioxide emissions from the national energy system.

The results in this paper provide important information for forecasting the structure of energy supply in Australia over the next decade.

**Defining the target**

Meeting the mandated target by 2010 will require a 2 per cent increase in the share of renewable electricity generation on top of the 1997 base. This translates into an aggregate target for renewable electricity generation at 2010 defined in the legislation at 9500 GWh — expected to equal about 4 per cent of total electricity generation at 2010.

Electricity generation from a range of technologies and sources may be used to meet the target. In particular, the following technologies and sources will be eligible under the measure where used for electricity generation:

- solar (for example, grid linked photovoltaics and steam generating solar thermal capacity);
- wind;
- ocean, wave and tidal;
- hydro;
- geothermal;
- biofuels (landfill gas, biogas, biomass);
- specified waste (biomass byproducts of agricultural crops but excluding broad scale land clearing for agricultural purposes; biomass byproducts of sustainably managed forestry operations; biomass byproducts of food processing and production industries; sewage treatment; biomass component of mixed municipal wastes; other biomass wastes as approved by the regulator);
- pumped storage hydro;
- renewable stand alone power supply (RAPS) systems;
- cofiring renewables with fossil fuels; and
- fuel cells using a renewable fuel.
The list also includes solar boosted water heating but only where the electricity displaced by its use is fossil fueled. This means that solar boosted water heating in Tasmania is effectively excluded from target because Tasmania’s electricity is overwhelmingly based on hydro resources assumed to have a greenhouse gas emissions coefficient of zero.

In section 40 of the Act, the target is defined not only for the year 2010 but for a ‘phasing in’ period between 2000 and 2010. Recognising that investment commitments in eligible technologies to 2010 will require support during a substantial part of the lifetimes of those assets, the target period — but not the level of the target — has been extended to 2020 in the legislation.

**Operation of the scheme**

Under the legislation, electricity retailers and other large consumers will each be required to purchase a certain proportion of their electricity requirements from ‘eligible’ new and renewable electricity sources. The proportion increases from 0.24 per cent in 2001 to approximately 4 per cent in 2010 — consistent with the overall national target for renewables.

Least cost achievement of the target is made possible by the use of a system of tradable renewable electricity certificates. Under the legislated system, renewable electricity certificates are created when electricity is generated using the eligible technologies and sources. Electricity retailers and other large consumers can purchase these certificates to make up any shortfall in physical purchases of eligible renewable electricity. If renewable electricity is expensive in some locations then large consumers in those places can purchase renewable electricity certificates generated in lower cost locations to minimise the cost of meeting their target. This implies that the marginal costs of additional renewable electricity generation would be equalised across sources. The AGO notes:

‘… trading of renewable energy certificates overcomes the need for each individual liable party to physically source renewable energy in order to meet their liabilities. Renewable energy will be able to be generated wherever it is most cost-effective to do so, or where the renewable resource is available. The certificates arising from that generation will be able to be traded nationally to acquit the liability of individual liable parties.’ (AGO 2000)

The price of a renewable electricity certificate must be sufficiently high to cover any financial losses associated with generating the last unit of additional electricity generated. In this way, returns from producing the certificates act as consumer financed subsidies for renewable power generation. Penalties for noncompliance with the target by major consumers are set at $40 /MWh, setting an upper limit on the price of the certificates. However, this amount is estimated as being somewhat above the expected marginal loss associated with additional renewable power generation under the target (MMA 1999)
implying that the penalty is not expected to constrain certificate prices. Penalties will be redeemable if compliance is achieved within three years.

The cost minimising properties of a tradable permit scheme are shown theoretically in Montgomery (1972) and are also discussed in Hinchy, Fisher and Graham (1998) in the context of climate change policy. As noted by Montgomery, the least cost outcome depends on the transaction costs associated with the scheme being sufficiently low and the absence of significant market power in certificate and related markets. Several studies internationally have shown how a tradable certificates scheme can be applied in the case of renewable electricity targets (for example, Clemmer, Nogee, Brower and Jefferis 1999). In Australia, experimental simulations have been conducted for the AGO (MMA 1999).

## Modeling implementation of the target

Major aspects of the technological and cost characteristics of the forms of renewable electricity included in the Australian MARKAL database are listed in table 3. This information

<table>
<thead>
<tr>
<th>Technology</th>
<th>State</th>
<th>Capital cost</th>
<th>Availability factor</th>
<th>Averaged unit cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bagasse, existing</td>
<td>NSW, Qld</td>
<td>a</td>
<td>0.15</td>
<td>15</td>
</tr>
<tr>
<td>Bagasse + waste, new</td>
<td>NSW, Qld</td>
<td>1500</td>
<td>0.80</td>
<td>28</td>
</tr>
<tr>
<td>Bagasse</td>
<td>Qld</td>
<td>1500</td>
<td>0.40</td>
<td>38</td>
</tr>
<tr>
<td>Wind power</td>
<td>NSW, Qld</td>
<td>1400</td>
<td>0.25</td>
<td>46</td>
</tr>
<tr>
<td></td>
<td>SA</td>
<td>1400</td>
<td>0.32</td>
<td>36</td>
</tr>
<tr>
<td></td>
<td>Tas</td>
<td>1400</td>
<td>0.40</td>
<td>29</td>
</tr>
<tr>
<td></td>
<td>Vic</td>
<td>1400</td>
<td>0.32</td>
<td>36</td>
</tr>
<tr>
<td></td>
<td>WA</td>
<td>1400</td>
<td>0.32</td>
<td>49</td>
</tr>
<tr>
<td>Small hydro</td>
<td></td>
<td>2300</td>
<td>0.45</td>
<td>48</td>
</tr>
<tr>
<td>Biomass into coal capacity</td>
<td>NSW,Qld,Vic,WA</td>
<td>380</td>
<td>0.90</td>
<td>23</td>
</tr>
<tr>
<td>Landfill gas</td>
<td>NSW,Qld,SA,Tas,Vic,WA</td>
<td>2400</td>
<td>0.90</td>
<td>24</td>
</tr>
<tr>
<td>Municipal solid waste</td>
<td>NSW,Qld,SA,Tas,Vic,WA</td>
<td>3000</td>
<td>0.85</td>
<td>39</td>
</tr>
<tr>
<td>Municipal waste water</td>
<td>NSW,Qld,SA,Tas,Vic,WA</td>
<td>2400</td>
<td>0.85</td>
<td>33</td>
</tr>
<tr>
<td>Wet waste</td>
<td>NSW,Qld,Vic,WA</td>
<td>3000</td>
<td>0.90</td>
<td>38</td>
</tr>
<tr>
<td>Wood waste, forestry residues</td>
<td>NSW,Qld,SA,Tas,Vic,WA</td>
<td>3000</td>
<td>0.85</td>
<td>60</td>
</tr>
<tr>
<td>Black liquor</td>
<td>NSW,Tas,Vic</td>
<td>2500</td>
<td>0.20</td>
<td>124</td>
</tr>
<tr>
<td>PV grid connected</td>
<td>NSW,Qld,SA,Vic,WA</td>
<td>4500</td>
<td>0.18</td>
<td>209</td>
</tr>
<tr>
<td>PV RAPS</td>
<td>NSW,Qld,SA,WA</td>
<td>5300</td>
<td>0.22</td>
<td>200</td>
</tr>
<tr>
<td>Solar thermal</td>
<td>NSW,Qld,SA,WA</td>
<td>2100</td>
<td>0.22</td>
<td>88</td>
</tr>
<tr>
<td>Energy crops</td>
<td>NSW,Qld,SA,Tas,Vic,WA</td>
<td>2800</td>
<td>0.50</td>
<td>88</td>
</tr>
<tr>
<td>Crop waste</td>
<td>NSW,Qld,SA,Tas,Vic,WA</td>
<td>2880</td>
<td>0.50</td>
<td>127</td>
</tr>
</tbody>
</table>

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**a Source:** Australian MARKAL database. **b Capital charge reflects 8 per cent real rate of return and debt repayment over the life of the station. c An existing technology with its capital costs ‘sunk’. d The capital costs of PV technologies and wind power (less so) are assumed in the Australian MARKAL database to decline significantly over the period 2000–10. See table 5. e For the intermediate season during the daylight period (NSW conditions).
was incorporated following advice from a specialist in the area (Redding 2000). Note that the ‘average unit costs’ as specified in the table have been calculated outside the model and, in addition to asset lifetimes and availability factors, assume a required rate of return of 8 per cent real — numerically equal to the default value of the discount rate specified in the database.

Basic scenarios

The modeling analysis for this paper is confined to renewable electricity generation and therefore excludes solar boosted water heating. The contribution of this technology to achieving the target has been estimated external to MARKAL, based on information provided by McLennan Magasanic (personal communication).

At 2010 (and beyond) the contribution of solar boosted water heating is assumed to be 616 GWh, compared with 274 GWh in 2009. For modeling the mandated target, these amounts are subtracted from the overall target for each year and the remainder is allocated over the remaining eligible technologies and sources using the MARKAL framework. The implied targets (excluding the assumed adoption of solar boosted water heating) for each year are shown in table 4.

Two basic scenarios are used to illustrate the impacts of the renewables target:

- ‘reference case’, with no target imposed on additional renewables based electricity output;

The projection period is to 2035 so as adequately to reflect project lifetimes. In both scenarios, the contribution of different technologies to electricity generation is assumed to be achieved at least cost over the period to 2035. In modeling the mandated renewables target, this approach is consistent with the theoretical cost minimising properties associated with the tradable certificate scheme described above.

The reference case provides a benchmark against which the impact of the target can be gauged. It should be noted that the reference case does not include the impacts of other potential future climate change policies or related government expenditures. For example,

<table>
<thead>
<tr>
<th>Year</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>2009a</th>
<th>2010–20a</th>
</tr>
</thead>
<tbody>
<tr>
<td>GWh</td>
<td>300</td>
<td>1 100</td>
<td>1 800</td>
<td>2 600</td>
<td>3 400</td>
<td>4 500</td>
<td>5 600</td>
<td>6 800</td>
<td>7 826</td>
<td>8 884</td>
</tr>
</tbody>
</table>

* a Implying a reduction corresponding to savings in fossil fueled 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.
if the renewables target were imposed in conjunction with a greenhouse gas permit trading scheme at some point in the future, results would be different from those obtained in this study.

Results from the MARKAL analysis

Total output from eligible renewable electricity technologies

Table 5 shows the output and shares of each type of renewable electricity for the base period, the reference case at 2010 and for the mandated target at 2010. Trends in the total levels of electricity output from renewable sources over 2000–20 are illustrated in figure 2 for both the reference case and the mandated target case.

<table>
<thead>
<tr>
<th></th>
<th>Reference case</th>
<th></th>
<th>Mandated target case</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2000</td>
<td>2010</td>
<td>2010</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>TWh</td>
<td>% shares</td>
<td>TWh</td>
<td>% shares</td>
<td>TWh</td>
</tr>
<tr>
<td>Bagasse – sugar mills</td>
<td>914 4.6</td>
<td>808 3.9</td>
<td>3611 12.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydro and pumped storage</td>
<td>17 992 90.8</td>
<td>18 303 88.1</td>
<td>19 028 68.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wind</td>
<td>67 0.3</td>
<td>67 0.3</td>
<td>1250 4.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biomass cofiring</td>
<td>0 0.0</td>
<td>0 0.0</td>
<td>814 2.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>‘Municipal’ biomass</td>
<td>622 3.1</td>
<td>883 4.3</td>
<td>2500 9.0</td>
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<tr>
<td>Forestry residues and wood waste</td>
<td>153 0.8</td>
<td>622 3.0</td>
<td>617 2.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>67 0.3</td>
<td>81 0.4</td>
<td>89 0.3</td>
<td></td>
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<tr>
<td>Total</td>
<td>19 814 100.0</td>
<td>20 764 100.0</td>
<td>27 908 100.0</td>
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</table>
The base period is dominated by hydro reflecting Tasmanian electricity generation which is currently almost wholly dependent on hydro and an averaged value of output for the Snowy Mountains Hydroelectric Scheme which supplies peak load electricity and reserve capability mainly to the New South Wales and Victorian systems. The single next most significant contribution is from bagasse based cogeneration from sugar mills. This is followed by the group of technologies under the heading of ‘municipal’ biomass, mainly landfill gas and, to a lesser extent, municipal waste water. Other technologies, including wind, have remained minor.

In the reference case over the period 2000 to 2010, renewable electricity generation is projected to grow by a total of 4.8 per cent. At 2010, in the reference case hydro continues to dominate, with its share falling slightly to 88 per cent of all renewable electricity. The bagasse contribution also falls slightly on the assumptions that some existing capacity reaches the end of its useful life and that, in some regions, other forms of renewable electricity generation such as forestry residues and wood waste become increasingly cost effective. The share of electricity from forestry residues and wood waste in total renewables rises from 0.8 per cent to 3 per cent under the reference case. Under the mandated target, the increase in renewables over the period 2000–10 totals 41 per cent, reflecting the assumed target.

With the introduction of the mandated target, several of the ‘new’ renewables begin to make substantial contributions. Compared with the reference case, the share of ‘bagasse – sugar mills’ (including supplementary use of wood waste) increases from 4 per cent to 13 per cent. Also the share of ‘municipal’ biomass rises from 4 per cent in the reference case to 9 per cent under the mandated target. Significant contributions are made by wind, new hydro and biomass cofiring. Reflecting the private and public costs associated with installing new hydro capacity, the share of hydro power in total renewables is projected to fall by 20 percentage points under the mandated target. However, there is some expansion in total hydro electricity generation relative to the reference case associated with improvements to process efficiency in existing hydro plants and new ‘small hydro’ schemes.

The mandated target was found to induce only zero or small additional contributions from the remaining eligible technologies, including a range of high cost ‘eligible’ technologies such as photovoltaics and solar thermal. Nevertheless, as discussed below, some contributions from these technologies can be expected as a result of separate assistance programs. Also, there may be some regions — not accounted for in the modeling — where more substantial renewable electricity generation from the higher cost technologies may emerge. Also, the results in table 3 do not include a substantial contribution to the target from solar boosted hot water systems. This contribution is discussed in the context of table 4.

The change in quantities generated and shares arising from the mandated target are consistent with the ranking of averaged unit costs in table 3. For example, with unit costs in the
range $15–38 / MWh, bagasse based electricity from sugar mills is among the cheapest forms of eligible electricity generation. It therefore achieves the greatest increase in share under the mandated target.

In achieving the mandated target at least cost, factors in addition to the unit cost of each technology type, as reflected in table 4, can be relevant. These additional factors include upper limits on particular types of capacity or electricity output available from the eligible technologies. These upper limits are of particular significance where averaged unit costs as indicated in table 2 are on the low side — for example, in the case of biomass used as a supplementary fuel in existing coal fired capacity. These limits can be set, for example, by

- availability of economically accessible biomass inputs (such as forest waste and various forms of municipal waste);
- externally defined level of activity of a ‘joint product’ (for example, process steam required in milling sugar cane); and
- availability of suitable sites (for example, minihydro or expansions to existing hydro).

Also, in the case of primary energy sources that are intermittent — such as wind — penetration levels will be limited compared with electricity sources that have a similar average cost but more reliable supply.

**Carbon dioxide emissions**

At 2010, the carbon dioxide emission reduction for the energy sector as a whole attributable to the mandated target (relative to the reference case) is estimated at 6.6 million tonnes of carbon dioxide.

The amount of emission reduction depends on the extent to which the additional renewables replace fossil fuel based electricity. The greatest reduction from the measure will occur where the output displaced is from coal fired capacity and the least when the output displaced is from a conventional renewable source. An intermediate case is where the displaced output is from electricity capacity using natural gas. The possible trends in relative shares of coal fired versus gas fired electricity in Australia over the 2000–30 projection period vary greatly among the states and are sensitive to a range of other assumptions. Making use of a MARKAL based analysis, these cases are discussed in detail in Naughten (2000).

**Additional resource cost of the mandated target policy**

An appropriate indicator of the cost of meeting the mandated renewables target is the increase in resource costs to the energy sector as a whole compared with the reference case. ‘Resource costs’ are costs excluding any taxes, subsidies or rents — including any
rents associated with the generation of renewable electricity certificates. The latter elements are transfers within the economy and therefore should not be included in a measure of costs or benefits to the Australian economy. Typically, resource costs will include differences between the reference case and policy scenario in relation to investment profiles, fuel costs and other variable costs.

The resource cost is expressed in constant prices (2000$A) and discounted back to 2000 at the 8 per cent real discount rate used in the Australian MARKAL analysis. Given these parameters, the total net discounted cost of the policy (compared with the reference case) was estimated at $749 million.

The net discounted cost of the mandated target in part reflects the capital costs associated with building additional renewable electricity capacity compared with the reference case. However, it also includes offsetting influences such as the reduced investment requirement for fossil fuel based electricity generation and the value of savings from reduced fossil fuel requirements in electricity generation. These components are shown in table 6.

The increased capital expenditure on renewable electricity capacity stemming from the mandated target policy had earlier been assessed in the range $1.8–3 billion (Redding 1999). Under least cost assumptions in Australian MARKAL, the (undiscounted) increase in capital expenditure (relative to the reference case) is estimated at the upper end of this range at $2.8 billion by the 2010 subperiod.

| Table 6: Components of total system discounted cost of meeting mandated target |
|-------------------------------------------------|-----------------------------|
| 2000A$                                          |                             |
| Domestic fuel costs                             | –1 096                      |
| Investment in supply                            | 1 440                       |
| Other                                           | 405                         |
| Total costs                                     | 749                         |

Figure 3: **Annual increment in investment in supply due to application of Mandated target**
Averaged over five-yearly periods

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<td>$m</td>
<td>–300</td>
<td>–200</td>
<td>400</td>
<td>–100</td>
<td>–200</td>
<td>–300</td>
<td>–300</td>
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</table>
The effect of applying the mandated target on the investment profile for the electricity sector as a whole is illustrated in figure 3. This shows the initial positive effects (compared with the reference case) induced by expenditure on the additional renewable electricity capacity — offset to some extent by reduced investment in fossil fuel based capacity. Over the periods 2020 and 2025, the negative impact (relative to the reference case) of reduced investment in fossil fuel electricity generation dominates. This is because the additional generation of renewable electricity creates excess capacity in existing fossil fuel power stations compared with the reference case. As a result, the need for investment in fossil based capacity in these later years is reduced compared with the reference case.

**Concurrent forms of government assistance to new and renewable electricity projects**

Apart from the mandated target, other concurrent programs of government assistance to new and renewable electricity projects might be expected to influence actual future outcomes.

The reference case includes some recently installed new and renewable capacity already in place or definitely committed. These examples of technologies ‘eligible’ under the mandated target will therefore form part of the least cost solution in the reference case because their capital costs are treated as ‘sunk’ (and running costs are generally low).

Some of these programs are state government initiatives — for example, various ‘green power’ schemes. Others are federal government supported programs of assistance including:

- Photovoltaic Rebate Program (residential): up to $31 million available over the four year life of the program;
- Photovoltaic Rebate Program (community);
- Renewable Energy Commercialisation Program (RECP): a five year, $55.6 million competitive grants program (demonstration and commercialisation of innovative, substantially Australian renewable energy equipment, technologies, systems and processes).

ABARE’s consultant (Redding Energy Management, personal communication) advises that currently no more than 30 MW appears to be involved — including up to 10 MW for pilot plants involving solar booster add-ons to coal fired power stations and 6 MW for rooftop photovoltaics, or 10–20 MW for photovoltaics generally. The staging and certainty associated with increments of a proposed 120 MW wind power station in the Portland area (Victoria) was uncertain at the time of writing and has not been included in the reference case.
Conclusion

The first part of this paper referred the reader to several ABARE publications that have made use of MARKAL enhancements to more ‘realistically’ model energy markets, noting the consequences for carbon dioxide emissions.

The second part of the paper reported on a MARKAL based energy systemwide and ‘least cost’ analysis of the mandated renewables target policy for electricity from the eligible renewables. The results are broadly consistent with those found using a technology by technology economic assessment undertaken for the AGO on essentially the same data assumptions for each technology (Redding 1999). However, the modeling technique used here enables a ‘least cost’ assessment of the aggregate cost of the policy under various assumptions, and the aggregate carbon dioxide reduction while taking account of energy systemwide effects.

At the aggregate level, a key effect of the mandated renewables target is to bring forward the adoption time of these new and renewable technologies. In terms of the particular technologies, the contributions to the increment measured against the 2000 level were assessed. In order of share size as at 2010 these were projected as: bagasse fired cogeneration; wind; incremental hydro; biomass cofiring; and various forms of ‘municipal’ biomass.
Appendix A: Price elastic demand for energy services

The case of stringent greenhouse gas emissions abatement targets

MARKAL is distinguished from some other energy sectorwide models by its endogenising the influence of relative prices on the consumption of final energy. As indicated in the previous section, this is accomplished by the inclusion of an end use stage that specifies competing ‘demand devices’ that transform such final energy inputs into energy services. For example, the database typically specifies various types of cars with different costs, energy efficiencies and fuel inputs all competing to meet exogenously determined requirements for passenger-kilometres over the projection period.

However, standard MARKAL had long been criticised for the price and income insensitivity of these exogenously specified projected levels of energy services — that is, the summed outputs of these end use equipment for a given end use. Such an assumption became an obvious point of weakness with the increasing use of MARKAL — in the first half of the 1990s — in modeling policy scenarios that included a tight greenhouse gas emissions constraint on the energy system as a whole. With stringent carbon dioxide targets and in the absence of this sensitivity to price and income effects, the result of modeling with standard MARKAL was often some combination of:

- infeasible model solutions;
- implausibly high rates of carbon penalty (as shadow price on the target constraint), especially in later subperiods; and
- implausibly early or rapid apparent substitution toward technologies with both very high unit cost and low carbon intensities (for example, fuel cells, photovoltaics).

These sorts of results may of course have several explanations — notably the use of databases that were insufficiently rich with defensible technology options over the relevant projection period. However, price insensitive energy services were certainly one defect that required attention. ETSAP members and MARKAL researchers did so with at least three variants of an enhanced model: ‘Elastic MARKAL’ (Tosato 1980; Loulou & Lavigne 1995, 1996; Loulou 1994), MARKAL MACRO (Hamilton et al. 1992) and MARKAL MICRO (van Regemorter and Goldstein 1998). While the other two approaches require nonlinear programming, the ‘Elastic MARKAL’ approach requires only linear programming, as in standard MARKAL. ‘Elastic MARKAL’ was the variant used in conjunction with the Australian database in a study of the effect of including relatively stringent and then near term (2000 and 2005) greenhouse gas emissions constraints (Naughten 1995a).

Following the 1997 Kyoto Protocol, which inter alia deferred targets until 2008–12 — and especially subsequent to the more recent announcement by the United States of its
intention not to ratify Kyoto — ‘policy relevant’ rates of carbon penalty\(^1\) have accordingly been much reduced. Certainly that is the case compared with the much more stringent targets considered policy relevant in the early 1990s\(^2\). To that extent, this particular deficiency of standard MARKAL is typically of less consequence now than in those policy analyses of the early 1990s.

‘Rebound effects’ from exogenous or endogenous improvements in end use energy efficiency

There is a second potential application for which the price and income elasticities of energy services are relevant. This is the modeling of the so-called ‘rebound effect’ accompanying exogenous improvements in energy efficiency of end use technologies. In these cases, it is generally assumed that no target or penalty has been attributed to greenhouse gas emissions. Before debates in the energy economics research literature in the 1980s\(^3\), there had often been an implicit assumption that exogenous improvements in the energy efficiencies of end use technologies would fully translate into savings in energy inputs. Such an assumption is only valid if there is no consequent increase in the level of derived energy services consumed. Yet, if such an exogenous improvement in energy efficiency does occur, the unit cost of the energy service will decline. To the extent that this decline in unit cost occurs (as a result of the efficiency improvement) and the energy service has a price elasticity of demand significantly different from zero, we would expect a consequent increase in consumption of the energy service. In the context of energy analysis, this quite standard result of microeconomic mechanisms has been designated as the ‘rebound effect’.

When the aggregate effect of many such energy efficient technological changes and energy services is considered, an additional result may be an endogenous income effect reinforc-

\(^{1}\) Post-Kyoto, ‘carbon penalty’ is best interpreted as the price of internationally tradable emission permits. Use of carbon penalties is also a convenient reflection of the fact that greenhouse gas emissions as defined by Kyoto extend beyond carbon dioxide. In addition, in a tradable emission permits system, the same rates of greenhouse gas emissions penalty applicable to the economy as a whole (including nonenergy sources and sinks) will also apply to the energy system. These aspects had not always been well captured in earlier modeling that had applied targets to the energy system alone and in respect of carbon dioxide alone.

\(^{2}\) For example, a paper presented to the previous (September 2001) ETSAP Workshop (Eyckmans, van Regemorter and van Steenberghe 2001) estimated the price of internationally tradable emission permits necessary to meet the Kyoto target as declining from 1995US$22 / tonne carbon dioxide to as low as 1995US$10 / tonne carbon dioxide as result of the United States’ withdrawal.

\(^{3}\) See for example, the literature reviewed in Saunders (2000) and Greening, Greene and Difiglio (2000).

\(^{4}\) In practice, a more important effect of income increases may be deteriorating energy efficiencies associated with the ‘multi-attribute’ nature of many energy services. One of the most notorious examples in recent times is the strong income related growth in the sales and use of light commercial vehicles used for passenger transport — so-called SUVs. In the United States, SUVs now (2001) account for 25 per cent of the category of light trucks compared with 13 per cent in 1992 (that is, a growth of 14 per cent a year). If the fuel efficiency of SUVs matched that of cars, the fuel saving would be 225 000 barrels a day — that is, 1.2 per cent of the United States’ annual oil consumption of almost 20 million barrels a day. An example of treatment of the multi-attribute the issue in MARKAL was that of urban and nonurban buses and coaches (Naughten 1994).
ing the price effect. That is, higher real incomes\(^4\) *consequent* on this exogenous energy efficiency improvement will also expand consumption of energy services, thus tending to further dilute the energy savings from exogenous energy efficiency improvement alone. Such an income effect can be modeled in the nonlinear MARKAL MICRO model.

The endogenous form of energy efficiency improvement is perhaps more commonly encountered. This means not only price induced through taxes or carbon penalties, but by consumers (as investors in energy using equipment) simply choosing to tradeoff a more costly but also more energy efficient technology bearing in mind their discounted value of future energy savings. Such tradeoffs will occur on a larger scale when (discounted) future energy consumption is also associated with carbon penalties or energy taxes. However, they will still occur to some extent even in the absence of such penalties, although these tradeoffs will be viewed less favorably if implied discount rates on the energy savings, or hurdle rates on the associated investment, are high — this is an issue in modeling ‘no regrets’ greenhouse gas emissions abatement, to which we return below.

In these endogenous cases, there will be an offsetting *increase* in the unit cost of energy services, thus diluting or negating the price and income related ‘rebound effect’.

The price related ‘rebound effect’ case — involving an energy-capital tradeoff but no carbon penalty — was modeled in an ‘elastic’ version of Australian MARKAL (Naughten 1995b). In that study, the end uses made price elastic were road passenger transport and the major residential categories of demand.

However, first, a current limitation of such analysis is the absence of reliable and comprehensive data on price elasticities of demand for the relevant energy services. Second, as noted, the endogenous effects tend to offset a ‘rebound effect’ by increasing the unit cost of energy services. Bearing these two factors in mind, as well as the general use of only relatively low rates of carbon penalty in scenarios considered below, the version of MARKAL chosen for use in the research reviewed reflects inelastic energy services.
References


—— 2001, *Viability of Sugar Cane Based Ethanol*, ABARE Report to AFFA, Canberra, October.


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