Modelling Energy Futures Forum Scenarios Using ESM

CSIRO and ABARE

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Executive summary

The purpose of this report is to provide details of economic modelling using an Australian Energy Sector Model (ESM) to determine the potential outcomes of scenarios developed by the Energy Futures Forum. The Energy Futures Forum is a diverse group of energy and transport sector stakeholders who have come together in an initiative led by CSIRO to explore plausible scenarios and their implications for the nation's future

ESM was developed jointly by CSIRO and ABARE as part of a package of three economic models made available to the Energy Futures Forum for economic modelling of scenarios. The key role of ESM in this package of models is to provide additional detail on technology uptake in Australia that the other models do not provide. The primary focus of outputs is non-hydro renewable electricity generation technologies, distributed generation and road transport fuel and engine technologies.

For sectors such as distributed generation and road transport, this is the first time such model-based projections of technology uptake have been available in Australia for the same scenario set.

The scenarios include a reference case, several scenarios where carbon prices are imposed to achieve greenhouse gas emission reduction and a high oil price scenario.

The results indicate that under the Energy Futures Forum scenarios wind and biomass based electricity generation could play a key role in non-hydro renewable electricity generation. However, recognising the limits of the modelling and present knowledge, the potential for other renewable electricity generation technologies, such as solar photovoltaics, solar thermal and hot fractured rocks, to also play a significant role remains. Distributed generation, drawing primarily on natural gas as the fuel, is projected to contribute up to 15% to total electricity generation across most scenarios in the period to 2050 representing a potential shift away from the currently centralised focus of the power sector.

A variety of alternative transport fuels are projected to be taken up in the event of sustained high oil prices or with the introduction of carbon prices. The alternative fuels taken up include ethanol, hydrogen, gas to liquids diesel, biodiesel and compressed natural gas. At the same time, hybrid electric/internal combustion vehicles are also projected to account for an increasing proportion of road kilometres travelled.

The modelling results need to be considered with some caution. A key limitation of the modelling is that it only considers cost effectiveness and a limited set of constraints in projecting technology uptake. In reality community concerns and many other non-price factors not included in the modelling will influence the future technology choices individuals and businesses make.

ESM and the overall modelling framework

The purpose of this report is to provide details of economic modelling using an Australian Energy Sector Model (ESM) to determine the potential outcomes of scenarios developed by the Energy Futures Forum. The Energy Futures Forum is a diverse group of energy and transport sector stakeholders who have come together in an initiative led by CSIRO to explore plausible scenarios and their implications for the nation's future.

ABARE and CSIRO were not involved with the scenario development process of the EFF project with the exception that ABARE developed one scenario (scenario 3, see Ahammad et al. 2006). The scenarios modelled in this report do not necessarily reflect the views of CSIRO or ABARE.

The modelling package provided to the Energy Futures Forum was designed to be able to provide projections at the global, national and sector levels. This approach recognises the importance of global drivers in the Australian energy sector but also the need to understand the options, resources and constraints specifically available to or affecting Australia when it responds to those drivers.

Three models were employed to ensure coverage of inputs and outputs that ranged from a global perspective to an Australian energy sectoral level. Two of the models were existing models provided by ABARE. A third was co-developed by ABARE and CSIRO specifically for the project to provide greater coverage of energy technologies.

1. The global trade and environment model (GTEM) is a dynamic, multi-region, multi-sector, general equilibrium model of the world economy developed by ABARE to address policy issues with long term, global dimensions, such as climate change. A dynamic model such as GTEM is beneficial when analysing climate change policies, since both the timing of policy implementation and the adjustment path that economies follow are highly relevant in the climate change policy debate. A detailed description of the model's theoretical structure is contained in Pant (2002).

2. Ausregion is ABARE's dynamic computable general equilibrium model of the Australian economy that depicts the eight states and territories, as well as sub-state regions. Ausregion is designed to take full account of the interactions and interdependencies between sectors and elements of the economy[1].

3. ESM (Energy Sector Model) is an Australian energy sector model co-developed by ABARE and CSIRO for the project to provide additional modelling outputs, specifically the role of individual non-hydro renewable technologies, distributed generation, road transport fuel and engine technologies. GTEM is unable to provide such outputs; instead for example, it aggregates non-hydro renewable energy technologies under one category of technology.

   ESM is a partial equilibrium model of the electricity and road transport sectors solved as a mixed integer linear program. The road transport sector is modelled at the national level while the electricity sector is represented at state and territory levels, including trade between the National Electricity Market states.

Given the uncertainties presented by the future, together with the general limitations of modelling, no single approach can provide a complete analysis of the real world.

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[1] A full description of the model's theoretical structure can be read at: http://www.abareconomics.com/publications_html/models/models/models.html#region

The technology coverage in ESM is described in the following points:

- 15 centralised electricity generation technologies including various fossil fuel options with and without carbon capture and storage, nuclear, and renewables hydro, wind, solar thermal, biomass and hot fractured rocks
- 11 distributed electricity generation technologies including natural gas and biomass plants with and without cogeneration, diesel, fuel cells and solar photovoltaics
- Six road transport modes; passenger cars, four wheel drives (4WD), light commercial vehicles, rigid trucks, articulated trucks and buses
- Ten transport fuels; petrol, diesel, liquefied petroleum gas (LPG), compressed natural gas (CNG), petrol with 10% ethanol blend, diesel with 20% biodiesel blend, ethanol and biodiesel at high concentrations, gas to liquids diesel and hydrogen (from renewables)
- Two engine types; internal combustion and hybrid electric/internal combustion
- All vehicles and centralised electricity generation plants are assigned a vintage based on when they were first purchased or installed in annual increments.

For the purposes of assessing the uptake of distributed generation, end users were considered to be one of four groups; residential, commercial/services, industrial and rural.

All technologies may be assessed on the basis of their relative costs subject to constraints such as the turnover of capital stock, existing or new policies such as subsidies and taxes and market constraints such as the need for a minimum share of peaking plant in the case of electricity generation.

For given time paths of the exogenous variables that define the economic environment, the ESM model determines the time paths of the endogenous variables. Key endogenous variables include:

- Stocks and volume of investment in vehicles and electricity generation capacities,
- Prices of transport services and electricity,
- Taxes and subsidies from fuel market penetration constraints

The endogenous variables are determined using demand and production relationships, commodity balance definitions and assumptions of competitive markets at each time step for fuels, electricity and transport services, and over time for assets such as vehicles and plant capacities. With respect to asset markets, the assumption is used that market participants know future outcomes of their joint actions over the entire time horizon of the model.

A number of exogenous variables are passed to ESM from the interface with GTEM. Global scenario settings are applied in GTEM and a number of model outputs produced. A number of these outputs such as GDP[2] are used in ESM.

Figure 1 shows the relationships between the models and the outputs generated. The diagram shows a downward flow of outputs from the global model to both the national model and ESM. The bulk of outputs are derived from GTEM with Ausregion and ESM providing consistent supplementary outputs not available from GTEM.

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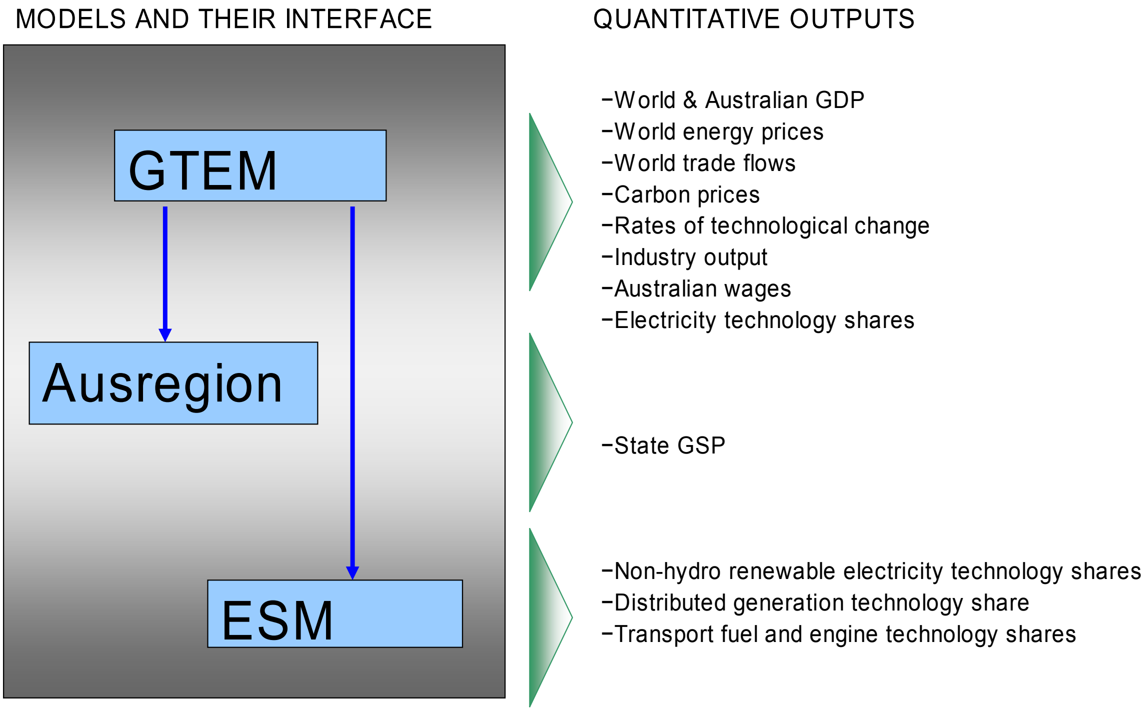
[2] GTEM projections of GDP account for the cost of greenhouse gas abatement but not the cost of damages from climate change

Figure 1: Interfacing GTEM, Ausregion and ESM and their respective outputs*



*Interface: common boundary shared by two devices across which data or information flows

Scenarios

The Energy Futures Forum first developed qualitative scenarios based on detailed storylines, with fictional characterisations, which were designed to act as a starting point for encouraging divergent thinking. Following the completion of these scenarios The Forum worked with ABARE and CSIRO to simplify the scenarios into packages that could be readily modelled by a narrow range of drivers.

It was agreed that there would be a reference case, 5 global greenhouse gas emission abatement ("mitigation") scenarios and a high oil price scenario. The scenario descriptions are produced below from Ahammad et al. (2006) with the exception of the High oil price scenario which was not included in that publication[3].

Reference case

The reference case aims to reflect a world scenario in which technological development and government policies progress along familiar paths, with the exception that globally all trade barriers are reduced by 70 per cent from their 2001 levels across the board by 2025, and there is no implementation of any significant new greenhouse gas emission reduction policies. However, most existing greenhouse gas reduction polices are assumed to apply.

High oil price

The high oil price scenario is characterised by a hypothetical world with an oil supply disruption leading toward a heightened world-wide concern for energy security. It is assumed that, under the scenario, the price of oil will increase from its present level to US$100/bbl (in today's dollar terms) by 2007 and remain at that level until 2014, after which it will approach its long-term much lower level over the remainder of the projection period to 2050. In assuming a low long-term oil price between 2014 and 2050, the EFF took the view that, given a period of sustained high oil prices, alternative liquid fuels would enter the energy market in large volumes. The market penetration of alternative liquid fuels is assumed to occur once their production infrastructure, have sufficient time to be built and the industry enjoys the economies of scale.

Scenario 1

This is a greenhouse gas abatement scenario which targets an emission path similar to that of the Special Report on Emission Scenarios (SRES) A1T scenario (IPCC 2000). In this scenario, global carbon dioxide emissions are targeted such that the global allowable emissions at 2050 will be 43 gigatonnes of carbon dioxide (Gt CO_2) consistent with reaching a CO_2 concentration stabilisation target of 575 ppm at 2100. This target represents a 35 per cent reduction in global carbon dioxide emissions relative to the reference case. The emission abatement target in scenario 1 is assumed to be achieved through the introduction of a globally harmonised carbon tax from 2030. Other greenhouse gas emissions including methane and nitrous oxide are assumed to adjust in response to the carbon tax. In this scenario, all global regions (with one exception) have access to all potential abatement technologies modelled in GTEM. The only exception to this technology option assumption is that Australia has no access to nuclear power during the projection period.

Scenarios 2a-2d

These are four greenhouse gas abatement scenarios, under different technology options and/or a differentiated abatement target for Australia (scenario 2d). In all four scenarios, global carbon dioxide emissions are targeted such that the global emissions at 2050 will be

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[3] The Ahammad et. al. (2006) report also refers to a "Scenario 3". Readers should note that this scenario was developed by ABARE rather than the Energy Futures Forum. Scenario 3 is similar to Scenario 2a except that the world emission abatement path to 2050 in Scenario 2a is achieved by a coalition of developed countries plus India and China rather than all countries. Due to its late inclusion in the project, this scenario was not examined using ESM. However, the carbon price levels and energy demand, if it were modelled in ESM, would be similar to those in Scenario 2d.

restricted to 39 Gt CO_2. Again, this targeted emission path is set so as to be consistent with a CO_2 concentration stabilisation target of 575 ppm at 2100. This emissions target represents a 40 per cent reduction in global CO_2 emissions relative to the reference case. The distinguishing features of the group 2 scenarios are as follows:

Scenario 2a – it is assumed that all regions have *access to all potential abatement technologies* modelled in GTEM. However, Australia is assumed to have *no* access to nuclear power during the projection period. The technology option assumption for scenario 2a, therefore, is similar to scenario 1.

Scenario 2b – similar to scenario 2a except that it is assumed that, under scenario 2b, *no region in the world will implement carbon capture and storage technologies* during the projection period. As is the case in scenarios 1 and 2a, Australia is assumed to have *no* access to nuclear power.

Scenario 2c – identical to scenario 2b above except that *Australia is assumed to have access to nuclear energy* under scenario 2c. It is assumed that, under scenario 2c, one small nuclear power plant begins operation in Australia around 2020, with the expansion of capacity building slowly off this low base.

Scenario 2d – Australia is assumed to reduce its own carbon dioxide equivalent emissions to 50 per cent below its 1990 levels by 2050, while the 2050 global carbon dioxide emissions target remains at 39.4 Gt CO_2. As for the technology options, the assumption of the global access to carbon capture and storage is maintained under scenario 2d. Also, Australia is assumed to have access to nuclear energy. As in scenario 2c, one small nuclear plant is assumed to start operating in Australia around 2020, with potential expansion taking place between 2020 and 2050.

Table 1 and Figure 2 outlines the key differences between the scenario modelling assumptions.

Figure 2: Emission paths: AIT and EFF Scenarios 1-2d

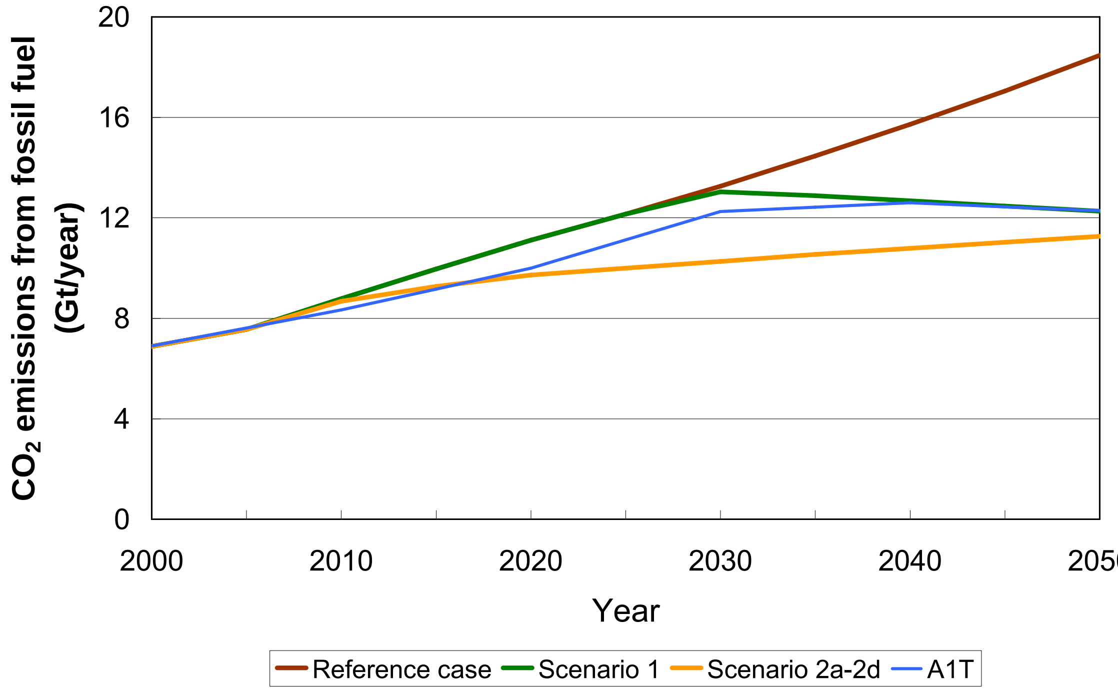


Table 1: Summary of scenario modelling assumptions

	Reference case	High oil price	Mitigation scenarios 1	2a	2b	2c	2d
Targeted global abatement of CO2 at 2050[a] (relative to the reference case)	NA	NA	35%	40%	40%	40%	40%
Introduction of climate change policy action	NA	NA	Late action: global partici-pation com-mencing in 2030	Early action: global partici-pation com-mencing in 2010	Early action: global partici-pation com-mencing in 2010	Early action: global parti-cipation com-mencing in 2010	Early action: global parti-cipation com-mencing in 2010
Differentiated abatement target for Australia	NA	NA	No	No	No	No	Yes: 50% below 1990 levels of CO_2 equivalent emissions by 2050
Availability of CCS, globally	NA	NA	Yes	Yes	No	No	Yes
Availability of nuclear power	NA	NA	No	No	No	Yes	Yes
in Australia A 70% across the board reduction in trade barriers by 2025, globally	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Temporary oil price peak of $100/bbl	No	Yes	No	No	No	No	No

a Excludes CO_2 emissions from bunkers.

Data assumptions

The most important drivers of the ESM modelling results are the carbon and oil price paths and macro-economically consistent projections of electricity and road transport services demand imported into the model as exogenous data from GTEM.

Carbon prices

A price on carbon dioxide and other greenhouse gases is needed in order to shift market decisions towards those that deliver the emission reduction in the scenarios. In the GTEM modelling, a globally harmonised carbon tax was used to ensure that the required level of abatement is achieved. (Other greenhouse gas emissions, including methane and nitrous oxide, are assumed to adjust in response to the carbon tax.)

This approach was adopted on the basis of its simplicity in application for modelling purposes. Via the modelling process, the carbon tax adjusts automatically to ensure that the world economy achieves the designated emission paths. This automatic adjusting is an important feature of a dynamic model, such as GTEM, as in other modelling contexts a carbon tax may be set to achieve an unknown level of emission reduction.

Because the carbon tax applied in GTEM automatically adjusts to ensure the emission path is achieved, it can also be interpreted as closely approximating the price of a permit (for an equivalent amount of emissions) under a tradable emissions permit scheme (see Ahammad et al. (2006) for more details).

For modelling purposes, the projected carbon taxes are imposed at the point of emissions to the atmosphere, without adjusting for existing taxes. The GTEM modelling does not take into account tax policy design issues or issues relating to compliance costs and revenue constraints.

Figure 3: Projected carbon prices from GTEM for the mitigation scenarios (A$/2005)

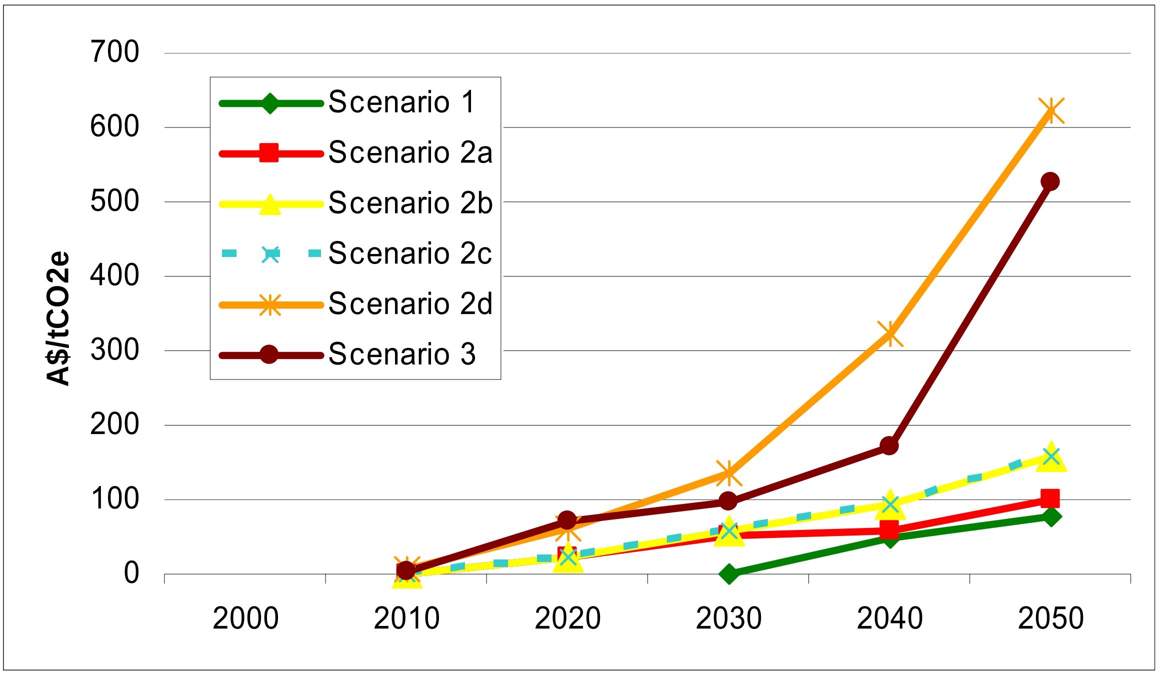
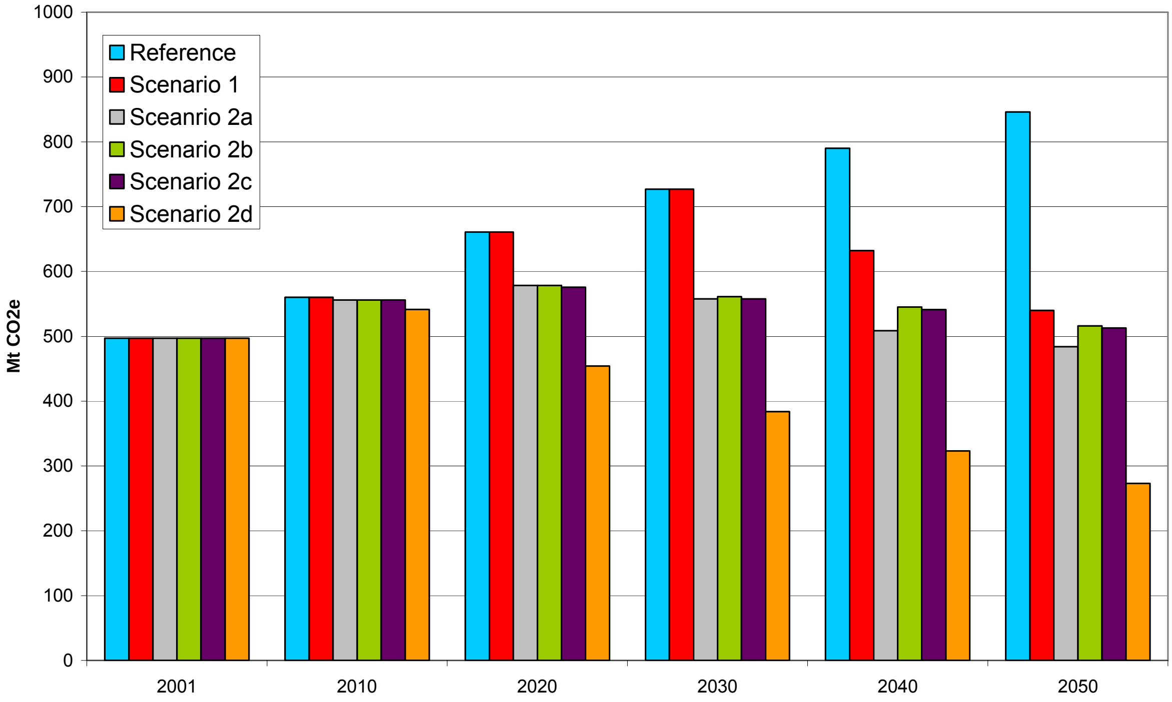


Figure 3 shows the projected carbon price paths over time for the mitigation scenarios. Note, the carbon price in scenarios 2b and 2c is the same because access or no access to nuclear power in Australia makes little difference to the global carbon price. The differences in the carbon price paths projected by GTEM reflect combinations of three factors:

- Differences in the timing at which the carbon price is imposed
- Differences in the global availability of low emission technologies
- Differences in the assumptions about the amount of additional greenhouse gas reduction taking place in Australia relative to the rest of the world

Figure 4 shows total Australian greenhouse gas emissions projected by GTEM across the whole economy that corresponds to the carbon prices imposed shown in Figure 3[4].

Figure 4: Australian greenhouse gas emissions by scenario



Oil prices

In the reference case and mitigation scenarios the world oil price is assumed to slowly decline from its present historically high levels in 2006 back towards its lower historical trend. In contrast, in the high oil price scenario, the price of oil increases from its present high level to US$100/bbl (in today's dollar terms) by 2007 and remains at that level until 2014, after which it will approach its long-term much lower level over the remainder of the projection period to 2050.

Electricity and transport demand

When carbon prices are imposed on the economy, electricity demand declines relative to what it would be without carbon prices because consumers respond by shifting their consumption to less carbon intensive goods and services, industry reduces the carbon intensity of its production process where possible and overall there is a slowing of economic growth. In the scenarios examined by the Energy Futures Forum, electricity demand is reduced by up to 20% by 2050. The level of electricity demand projected by GTEM for the mitigation scenarios is shown in Figure 5.

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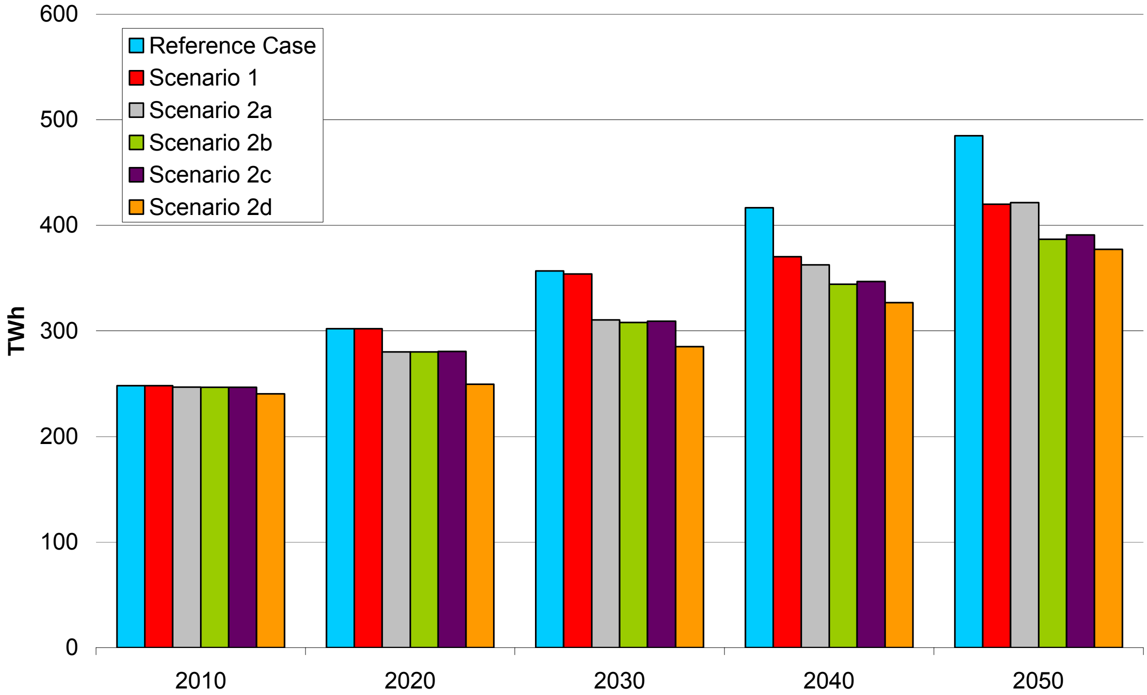
[4] Note that greenhouse gas emissions are higher in scenarios 2b and 2c because, in the absence of the option to use carbon capture and storage, emission reduction is higher cost in Australia relative to scenario 2a. As a result, additional abatement opportunities are taken up in other countries to ensure that the world stays on its global emission reduction path.

Electricity sector impacts of the high oil price scenario were not examined on the basis that it is not an important electricity generation fuel in Australia. However, it is acknowledged that growth in demand for electricity would likely slow during the period where the economy is subject to high oil prices due to the impact of slower GDP growth.

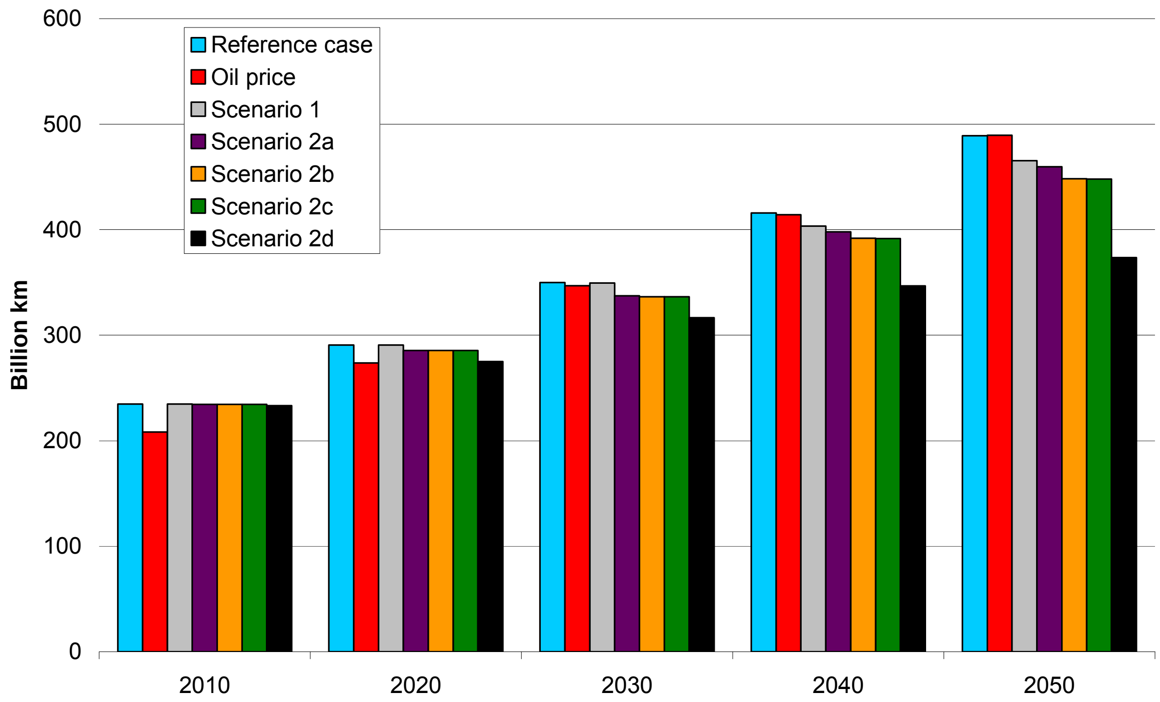
Figure 5: Electricity demand in the mitigation scenarios



Road transport demand to 2050 was assumed to be a function of Australian income and industry activity levels in GTEM. Up to 2020, the total assumed growth in reference case demand is in line with the BTRE (2005) which projects 289 billion road transport kilometres (Figure 6). Whilst recognising the potential, no attempt is made to predict the possible reduction in road transport demand from users seeking to shift to non-road transport such as rail.

For the high oil price scenario, projected transport demand declines in 2010 relative to the reference case but recovers as oil prices decline. For the mitigation scenarios, growth in transport demand is slower than the reference case from around 2020-2030 due to the negative impact of carbon prices on GDP growth and demand for carbon intensive goods and services.

Figure 6: Road transport demand across all scenarios



Technology shares

The shares of broad electricity generating technologies in total electricity generation that were projected to be taken up in the GTEM model were imposed as technology share assumptions on ESM. This means that the share of technologies such as coal and gas with and without CCS, nuclear, hydro and other renewables in total electricity generation to 2050 is an input rather than an output of the modelling process. Figure 7A-7F depicts the technology shares projected by GTEM for the Reference Case, Scenario 1 and Scenarios 2a-2d.

Given these technology shares are imposed, the main role of ESM, in terms of the electricity sector, is to determine:

- What types of renewable electricity generation technologies could potentially contribute to the broad non-hydro renewable technology share that was projected as an output of GTEM?, and
- What proportion of the projected electricity generation in GTEM could be from distributed rather than centralised electricity generation?

The road transport sector in GTEM does not determine detailed road transport fuel and engine technology shares and so the fuel and engine technology shares are projected in ESM.

Non-hydro renewable resource constraints

When considering various renewable electricity generation technologies, an upper limit to the take-up rate of each was set, based on intermittency or land availability.

In relation to biomass, costs associated with accessing the electricity grid and transporting feedstock[5] were taken into account. However, the issue of food-crop competition was not specifically addressed due to a lack of estimates available in the literature of what constraint

[5] Most forms of biomass have relatively low energy density, requiring larger volumes to be transported, stored and handled compared with the volumes of oil or coal that contain the same amount of energy

this might imply. The issue of impact on biodiversity was also not considered with most available land being considered part of the available resource (after taking into account its fertility). It should also be noted that long-term harvesting of biomass on a regular basis from the same site results in a depletion of soil nutrient levels. Careful management is required to provide a sustainable system and avoid the need to apply expensive and energy-intensive fertilizers.

Recognising the potential difficulty in managing intermittency associated with wind and solar energy, the contribution of each of these technologies was constrained to not exceed 20 per cent of total system generation capacity. There is some uncertainty about whether this constraint is at the right level. Wind is already at a high penetration in overseas countries and South Australia, suggesting the constraint may be too low. The highly probable future development of cost-effective electricity or energy storage would also play a large role in addressing intermittency issues. In the model assumptions, utilisation factors for wind and solar are generally around 25%. This means that to ensure wind can regularly contribute 1 MW of power, 4MW of capacity must be installed.

The uptake of wind technology may also be constrained by community concerns about visual impact, noise, and bird mortality.

Exploitation of hot fractured rocks or geothermal resources would not be affected by intermittency and the large available resource in Australia (assuming demonstration is successful) means that an upper limit on its uptake is not warranted.

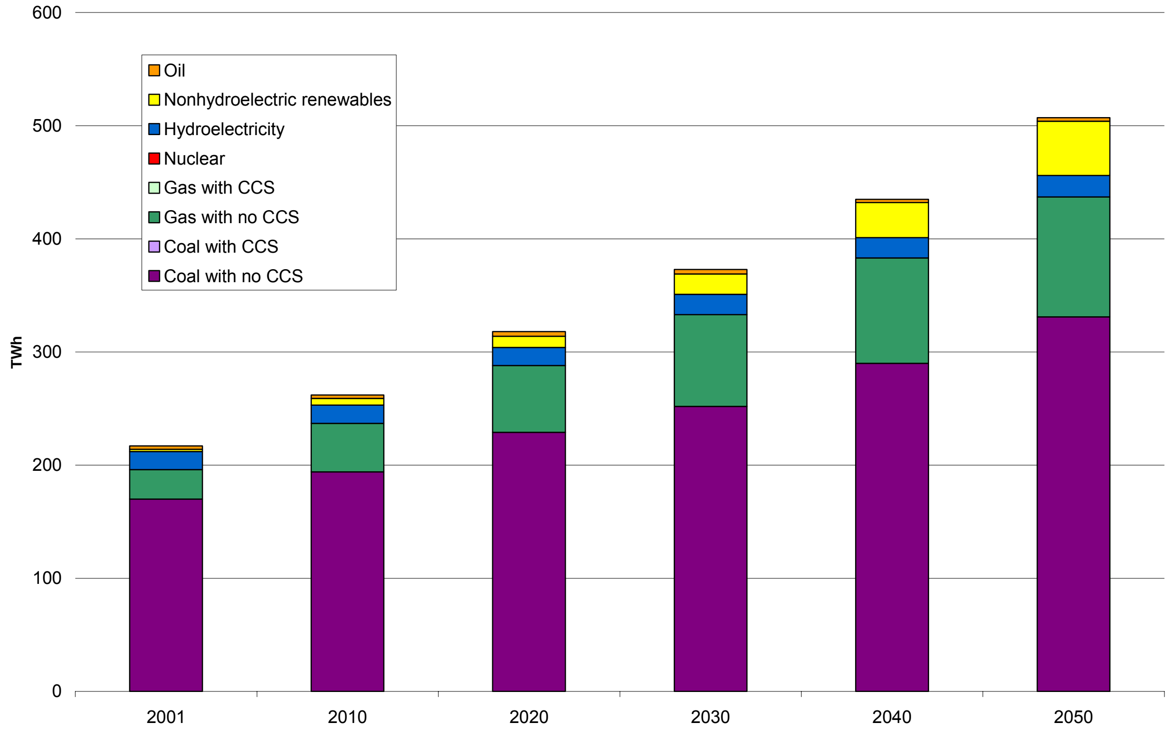
Other data

There are many data inputs that support the economic modelling commissioned by the Energy Futures Forum. There was a concerted effort by the EFF, ABARE and CSIRO to update the models with the latest intelligence on the structure of the global economy, energy prices, technology cost and performance characteristics and so forth. The data was pooled and sorted by the economic modellers.

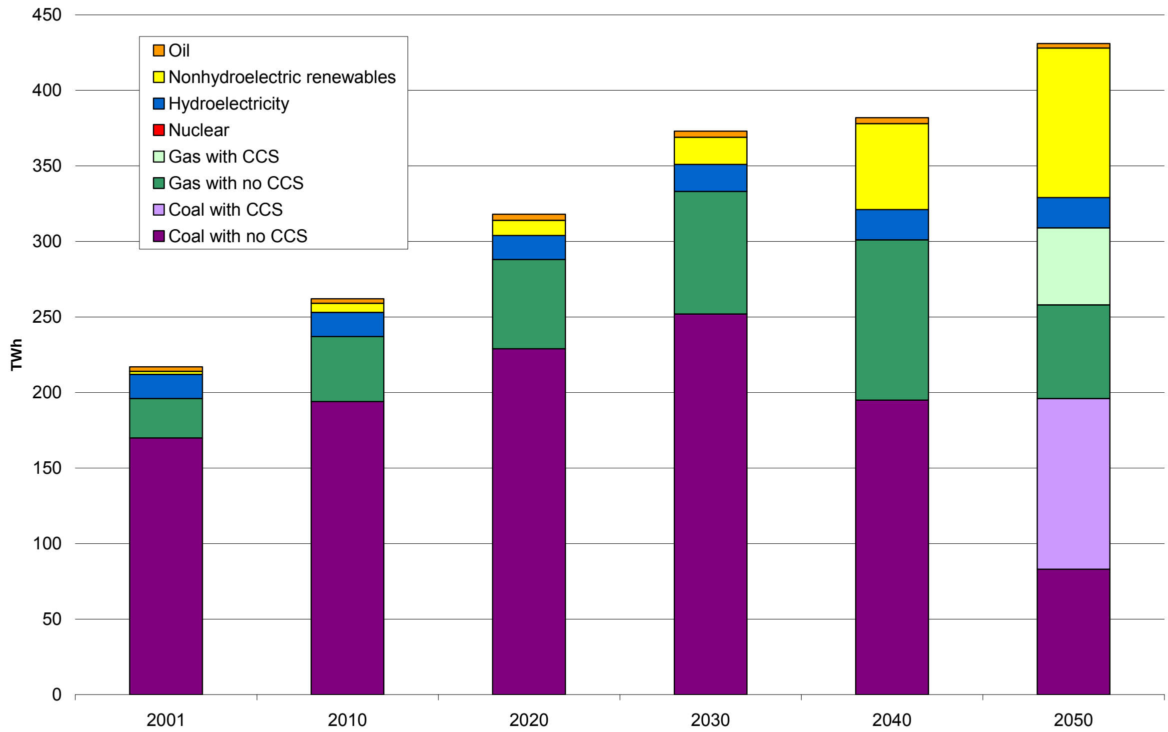
The project was also designed to permit EFF participants – many of whom are industry sector leaders – to supply data to the economic modellers on a commercial-in-confidence basis. The rationale was that such data could improve the veracity of the modelling. Some participants exercised this option, and as a result the modelling data is a mixture of open and confidential sources. All publicly available data is outlined, and referenced where possible, in this document and Ahammad et al. (2006).

Figures 7:Technology shares in Australian electricity generation by scenario to 2050

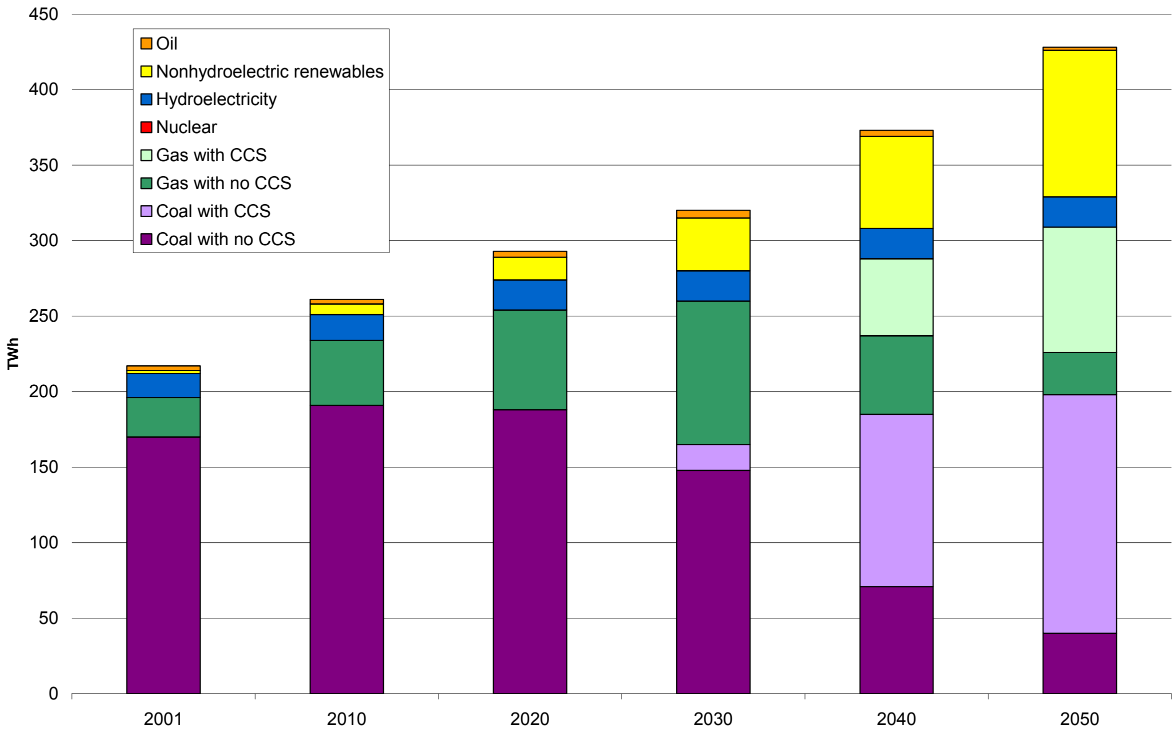
7A:Reference case - Technological development and government policies progress along known paths; no implementation of significant greenhouse gas emission reduction policies



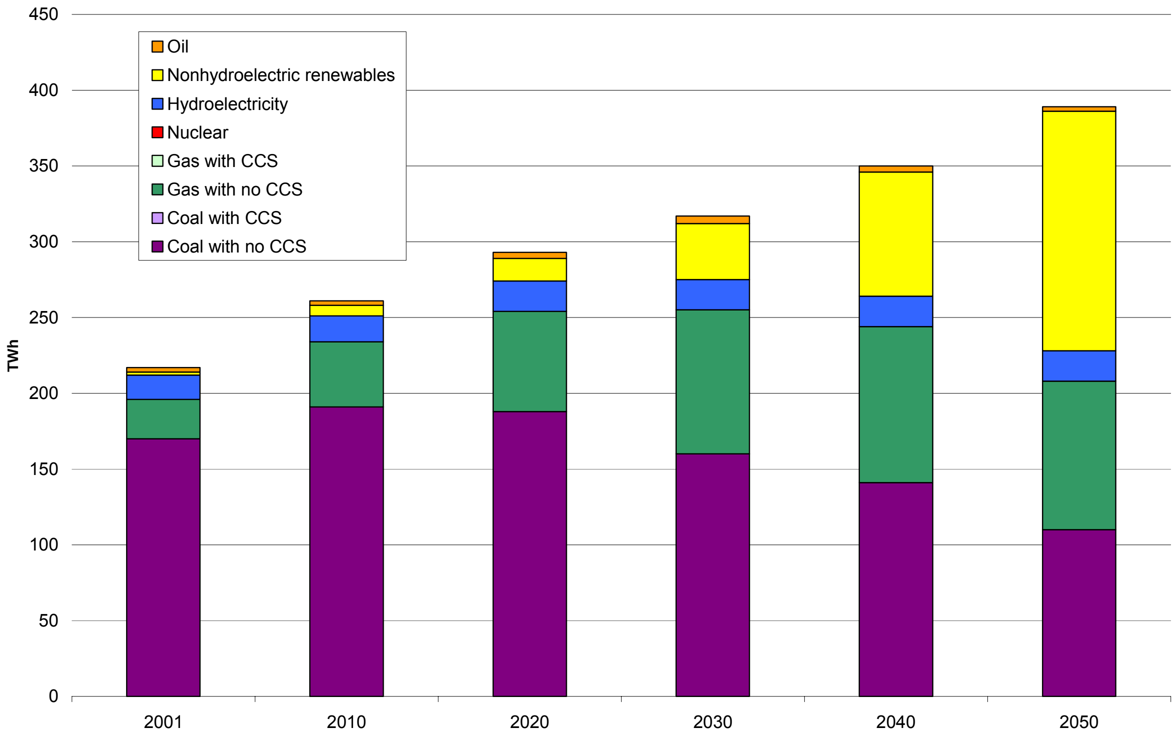
7B: Scenario 1 - Late action including all countries with a full range of abatement technologies except no nuclear in Australia



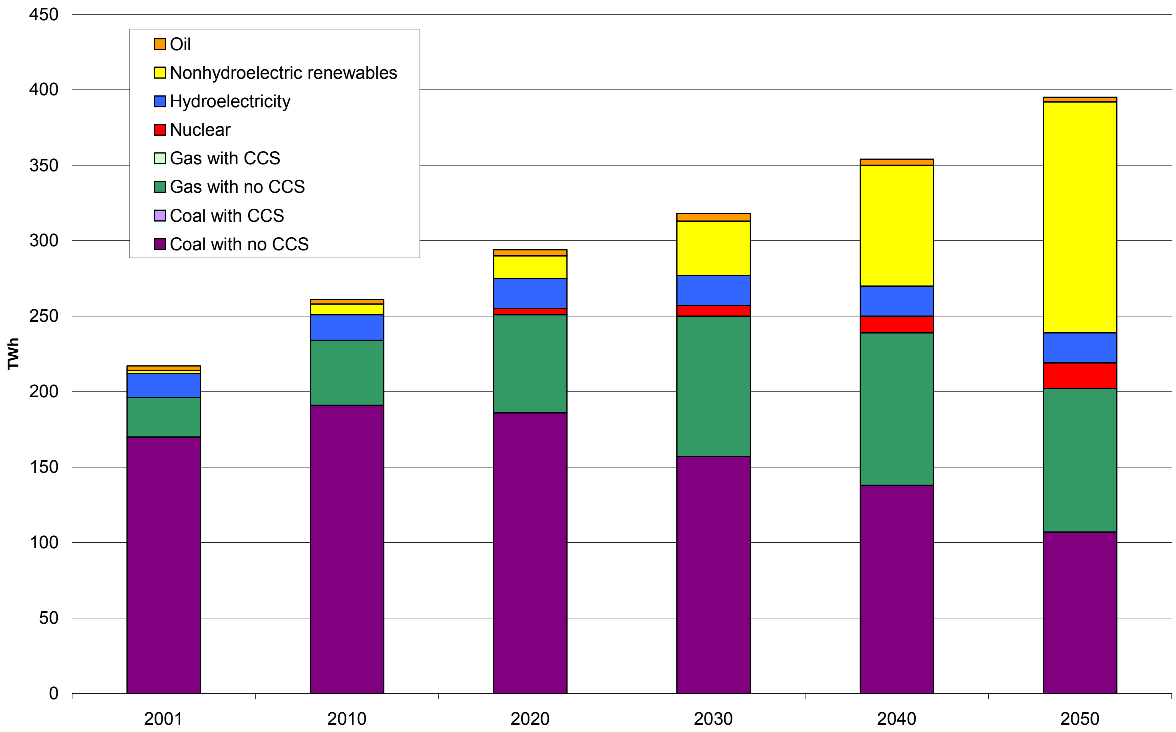
7C: Scenario 2a - Early action including all countries with a full range of abatement technologies except no nuclear in Australia



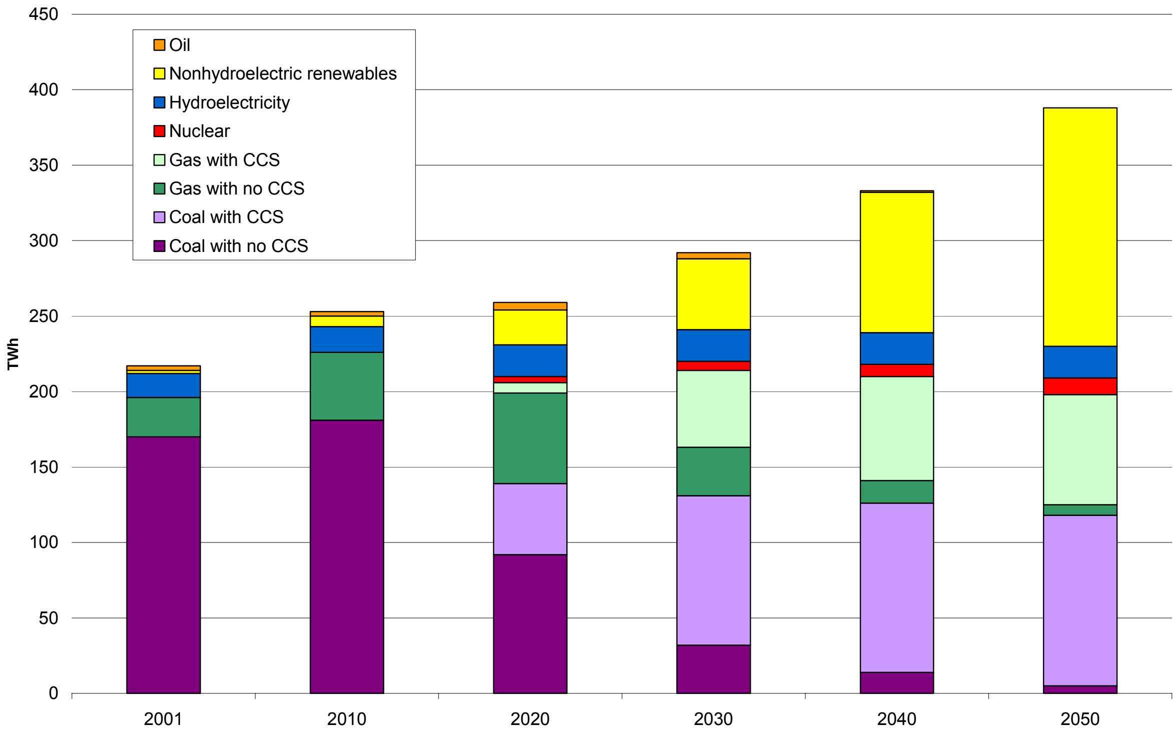
7D: Scenario 2b - Early action including all countries without CCS globally and no nuclear in Australia



7E: Scenario 2c - Early action including all countries without CCS globally but Australia can access nuclear



7F: Scenario 2d - Early action including all countries with a deep cut in Australia's emissions and all technologies available

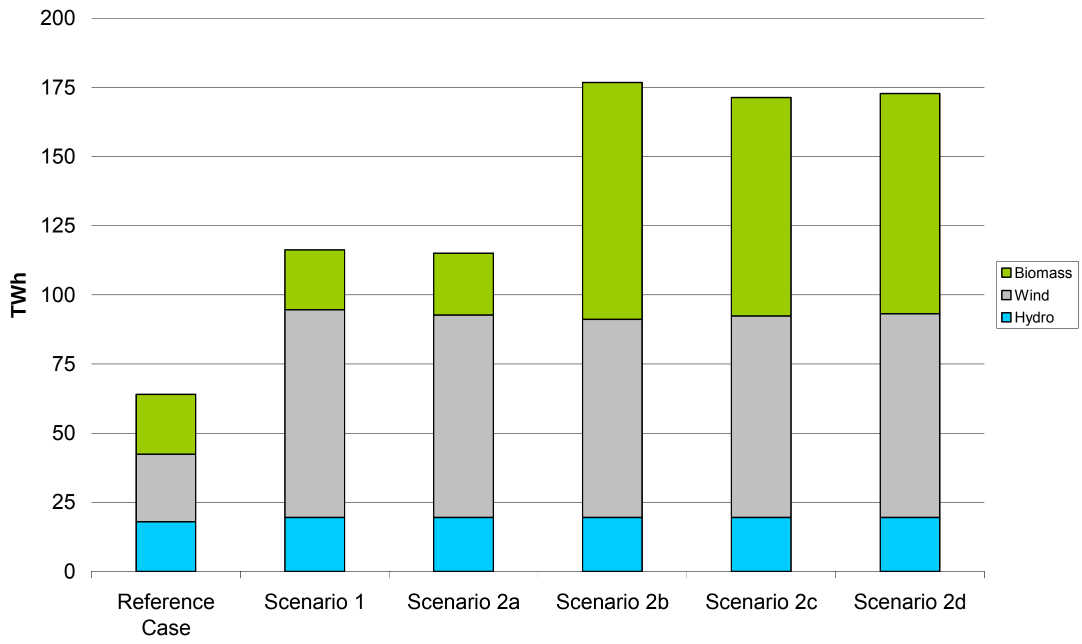


ESM results

Renewable electricity generation

Figure 8 shows the projected amount of electricity generation from renewable electricity generation technologies across the mitigation scenarios. The results indicate that wind and biomass would dominate non-hydro renewable electricity generation with no solar or geothermal resources making a contribution. The uptake of wind reflects its position as the lowest cost non-hydro renewable electricity generation source. If an upper bound of 20% of total electricity generation capacity had not been imposed, its share of output would have been higher still.

Figure 8: Shares of renewable energy technology categories taken up by scenario in 2050



Biomass is generally the next most competitive non-hydro renewable electricity generation source, although there is some cross over with some biomass resources being lower cost than some wind resources in the modelling assumptions. Biomass contributes up to 80 TWh of electricity generation. It can be argued that the biomass uptake shown is achievable without substantially reducing food production. Table 1 shows some calculations of a potential 100 TWh of available biomass resources that do not impinge on food-crop production. This is similar to the findings of Energy Strategies (2004) who estimate that all biomass crops and residues could together supply considerably more than 92 TWh of Australia's electricity by 2040, without competing with food production.

Table 2: Estimated biomass supply and potential electricity generation from various sources

Biomass type	Estimated biomass (t)	Net Heating Values (MJ/kg)	Energy Content: Fuel (PJ)	Energy Content: Thermal (PJ)	Electricity Generation (TWh)
Wood					
Forest harvesting residues	2986856	16.1	48.09	16.83	4.68
Uncommitted plantation resource	1220000	16.1	19.64	6.87	1.91
Uncommitted softwood plantation residue	260000	16.1	4.19	1.47	0.41
Uncommitted Native Forest residue	224000	16.1	3.61	1.26	0.35
Total estimated Sawmill residue	1796794	20.0	35.94	12.58	3.49
In-field Agricultural resources	55000000	18.0	990.00	346.50	96.26
Post-processing Agricultural resources	425000	18.0	7.65	2.68	0.74
Total	61912650		1109.11	388.19	**107.84**

Notes:

Wood

Estimated biomass for wood types from *Bioenergy Atlas of Australia* (BRS, 2002).

Net heating value for all types are taken from *Bioenergy Australia newsletter* (Biomass Taskforce, 2002). The net heating value for all types except Sawmill residue is the average of net heating values for wood - air dry, humid zone (15.5) and wood - air dry, dry zone (16.6). The net heating value for Sawmill residue is the net heating value for wood - oven dry (20.0). For the record, the net heating value of wood - wet, freshly cut: is 10.9.

In-field Agricultural resources

Includes: harvesting residue from oilseed; rice; grain legume; summer cereal; vegetable, and; winter cereal production.

Estimated biomass for harvesting residues from in-field agricultural resources, taken from *Bioenergy Atlas of Australia* (BRS, 2002).

A rule of thumb energy content of typical biomass was used for this broad category (18.0), taken from *Bioenergy Australia newsletter* (Biomass Taskforce, 1999).

Post-processing Agricultural resources

Includes: cotton trash; lucerne trash; rice processing trash (hulls), and; bagasse.

Estimated biomass for harvesting residues from in-field agricultural resources, taken from *Bioenergy Atlas of Australia* (BRS, 2002).

A rule of thumb energy content of typical biomass was used for this broad category (18.0), taken from *Bioenergy Australia newsletter* (Biomass Taskforce, 1999).

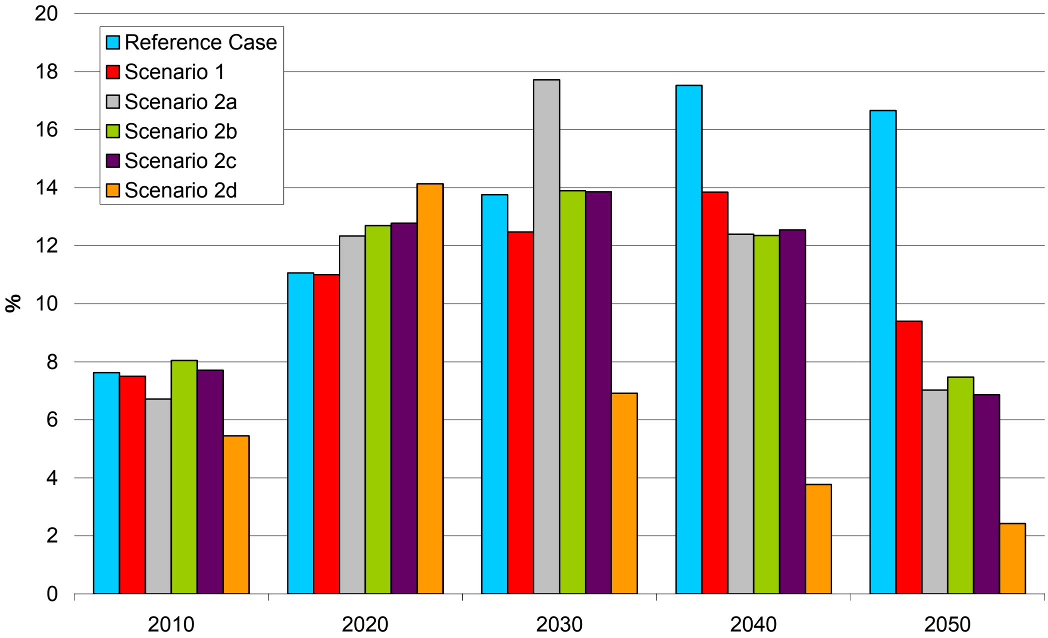
However, despite these assurances about the cost competitiveness of wind and the availability of biomass, it may be expected that Australia would see a more diverse set of renewable electricity generation technologies under the scenarios examined than has been projected by ESM. Concerns about availability of water and biodiversity impacts could limit uptake of biomass electricity generation in reality. Similarly the modelling does not take into account possible community concerns about the impact of wind on bird mortality and the aesthetics of the landscape.

If the shares of wind and biomass technologies are reduced, the balance could be taken up by solar and hot fractured rocks. Most solar technologies fit well into existing landscapes, particularly in urban areas and research and deployment continues to reduce their costs. Hot fractured rocks is yet to be fully demonstrated in Australia and so there is still much uncertainty around the cost of electricity from this technology. Were it to prove cost effective its output would not suffer from the intermittency of wind and solar and the potential resources are vast (Somerville et al., 1994). Other renewable energy technologies, not yet fully developed could also be expected to emerge in the period to 2050.

Distributed generation

Distributed generation represents a structural break from the current electricity generation system that is characterised by large centralised power generation located on the basis of being near a water or fuel source. Distributed generation is, by contrast, purposefully located near or at the end-user to reduce electricity transmission and distribution line losses and, ideally, to make use of waste heat from the electricity generation process. Using a broad definition of distributed generation that includes any generation that is located near the primary end-user the current share of distributed generation in Australia is estimated to be around 6 percent. This existing infrastructure consists mostly of gas and diesel fired plants, serving mines and other remote users as well as urban cogeneration plants which utilise waste heat for industrial purposes. Renewables such as wind and solar are also utilised but their volumes are relatively small. Solar hot water heating is significant in Australia and offsets electricity generation and natural gas consumption.

Figure 9: Share of distributed generation in total electricity generation by scenario



It was projected by ESM that distributed generation would expand its role in electricity generation in Australia to around 15 percent in most scenarios (Figure 8). The primary distributed generation technology projected to be taken up was natural gas-fired turbines with a cogeneration by-product of waste heat used to increase the overall efficiency and cost-effectiveness of the plant. Renewable distributed generation remained small, being too high cost in the early part of the projection period and being out competed by centralised renewable electricity generation in the latter part of the projection period. The uptake of distributed generation peaks around 2030. As carbon prices increase further towards 2050 the role of gas-fired distributed generation is reduced on the basis of emissions being higher than centralised renewables and coal or gas with carbon capture and storage (Table 3).

Table 3: Amounts of distributed electricity generation by fuel source (TWh)

		2010	2020	2030	2040	2050
Reference Case	Gas	17	31	46	70	78
	Diesel	2	2	3	3	3
Scenario 1	Gas	16	31	41	48	37
	Diesel	2	2	3	3	2
Scenario 2a	Gas	14	31	50	41	27
	Diesel	2	3	5	4	2
Scenario 2b	Gas	18	32	38	39	26
	Diesel	2	3	5	4	3
Scenario 2c	Gas	17	29	40	38	26
	Diesel	2	7	2	5	1
Scenario 2d	Gas	11	26	18	11	7
	Diesel	2	9	1	1	3

There are a number of uncertainties, not yet captured in ESM which would alter both the rate of uptake and types of distributed generation technologies taken up in the projection period. These uncertainties include:

- The emergence of integrated energy companies and the types of distributed generation technologies and service contracts they may seek to promote (e.g. emphasis on reducing peak demand on the grid would favour certain technologies)
- Local environmental restrictions (e.g. emission and noise)
- Emergence of new technologies suited to small scales (e.g. micro wind turbines, cost effective fuel cells and solar devices capable of being inexpensively incorporated into buildings)
- The electricity and waste heat demand load profile of different Australian end-user groups (e.g. different climatic conditions and different types of businesses)
- The impact of exposure to retail price volatility via smart meters (which signal changes in the electricity price during the day to households and business) and associated supply contracts which offer incentives to respond to daily price changes

Road transport fuels and engines

Petrol is the most dominant road transport fuel used in Australia with diesel and LPG ranking second and third respectively. In considering future changes to the market share of these fuels and the potential uptake of alternative transport fuels, it should be noted that, for the average user, the cost of fuel including excise only represents around 15% of the total cost of road transport services for the typical Australian passenger vehicle (which is the most dominant road transport mode). In the total fuel price, government excise of 38 cents per litre can represent 30-40% of fuel costs at petrol prices experienced in Australia in 2005-06. Note, a 38 cents per litre excise on petrol is roughly equivalent to a carbon tax of A$170/t$CO_2$ on petrol use. However, it is important note that fuel excise is not indexed in Australia. As a result, its real value will be reduced by around two thirds by 2050.

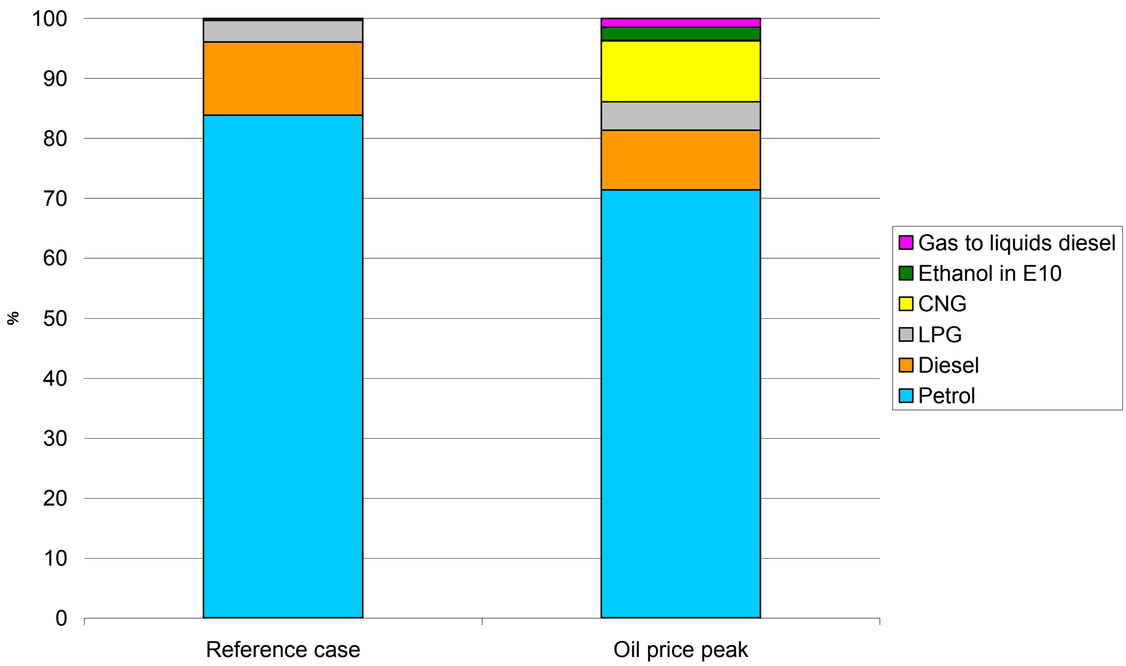
Whilst small in relation to passenger vehicle transport, fuel costs are more significant for users of commercial road transport. However, even in these road transport modes, the cost of the vehicle itself remains the most significant item. Other significant items are registration, insurance and maintenance. Some alternative fuels require incurring additional costs to the vehicle relative to conventional vehicles. These additional costs associated with alternative fuels can be more significant than the cost of the fuel itself when compared with conventional vehicles. For example, some gaseous alternative fuels require large storage tanks to maintain the same travel range.

Hybrid electric internal combustion vehicle engines can theoretically be applied to any fuel although models available in Australia in 2006 are petrol hybrids. Such engines increase the cost of the vehicle but can be expected to reduce fuel costs by one third to one half depending on the size of vehicles being compared.

The results discussed below represent projections from ESM where it has selected the most cost effective fuel and engine combination which minimises the total cost of road transport in light of changes to oil prices and imposition of carbon prices in the scenarios.

The results of the uptake of alternative fuels in 2010 in the high oil price scenario are shown in Figure 10. As oil prices increase to US$100/bbl in 2007 and remain at that level until 2014, this presents a significant period in which alternative fuel production capability can be brought to the market. Under this scenario, ESM projects that CNG[6], ethanol and gas to liquids diesel will come to occupy 11 percent of total kilometres travelled by 2010 compared to the less than 1% they represent in 2006. Use of LPG will also expand[7].

Figure 10: Uptake of alternative fuels in 2010 under high oil price scenario



For the greenhouse gas mitigation scenarios 1 and 2a-d the projected fuel shares are displayed for the year 2050 since this is when carbon prices are highest[8] (Figure 11). The results show that for scenarios 1 and 2a there is virtually no change in uptake of alternative fuels relative to the reference case. This is perhaps not surprising since the carbon prices in these scenarios would have only around half the impact of the current government fuel excise. However, in scenario 2b where carbon prices are nearly double those in scenario 1 and 2a, ESM projects an increased share of CNG at the expense of conventional Australian road transport fuels.

In scenario 2d where carbon prices are around 6 times those in scenario 1 and 2a, ESM projects a significant uptake of a variety of alternative fuels including CNG, ethanol, biodiesel

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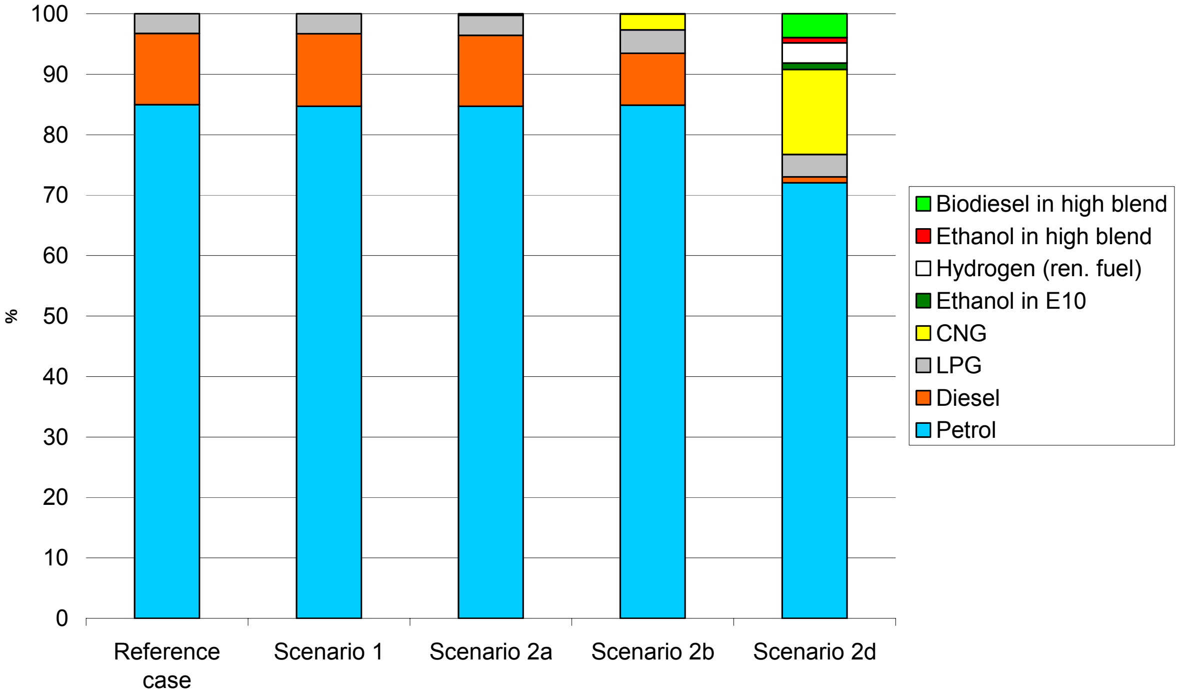
[6] It was assumed that the marginal price of natural gas available to producers of gas to liquids diesel and CNG would increase but not as much as the increase in the price of oil. In effect, it is assumed the domestic price of natural gas in Australia is not tied to international oil prices.
[7] Recently announced subsidies for new LPG vehicles and LPG retrofitting to existing vehicles were not included in the modelling as it was unclear for how long such subsidies would be available. Were they included in the modelling it would be reasonable to expect a greater role for LPG above that projected here.
[8] Results for scenario 2c are not shown. Scenario 2c has identical carbon prices to scenario 2b. Between the two scenarios there is some difference in demand for transport services due to differences in Australian GDP projected by GTEM. However, this does not significantly change the types of fuel and engine technologies projected to be taken up between the two scenarios. Scenario 2c was primarily designed to explore the uptake of nuclear power in Australia.

and hydrogen[9]. Both petrol and diesel shares are impacted but particularly diesel which is all but removed (ignoring use of diesel in high biodiesel blends). The reason for this may be that the economic benefit of diesel vehicle's normally lower running costs is diluted by the use of hybrid electric/internal combustion engines which make fuel costs a lower proportion of total road transport costs.

Figure 11: Uptake of alternative fuels in 2050 under the greenhouse gas mitigation scenarios

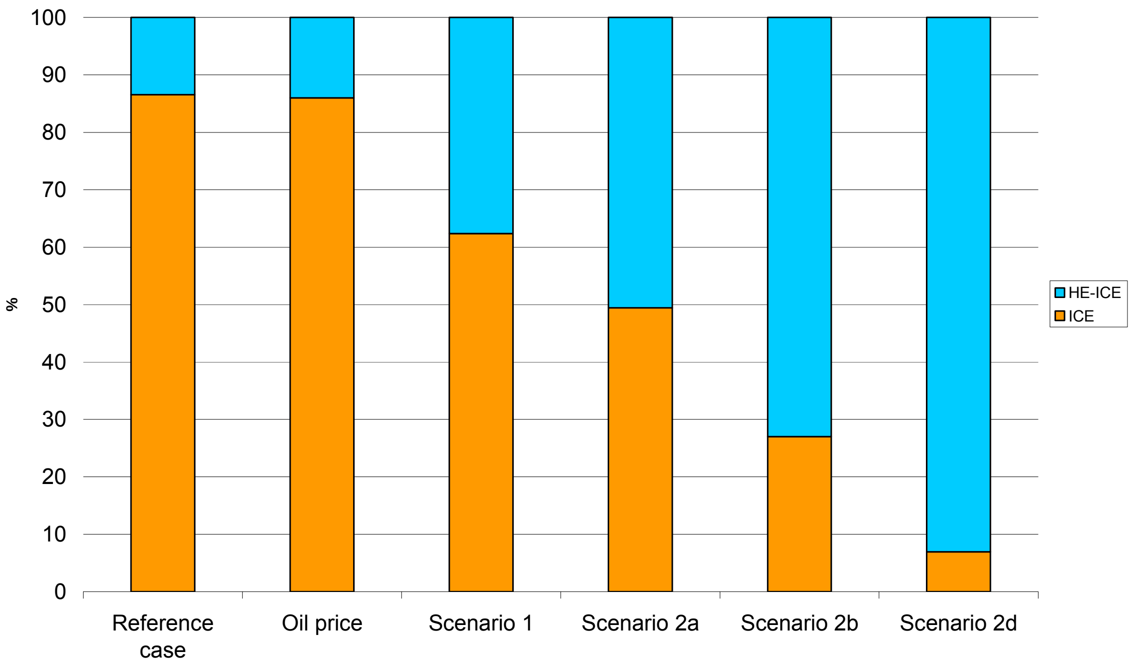


In terms of vehicles engine technologies, ESM selects between only internal combustion engines (ICEs) and hybrid electric internal combustion engines (HE-ICEs). Figure 12 shows the shares of these engine types projected to be taken up in each scenario by 2050. The results indicate that under the reference case which does not include carbon taxes or high oil prices, HE-ICE vehicles are projected to account for 14 percent of the vehicle kilometres travelled in Australia. The share of HE-ICE is only 1 percent higher under the high oil price scenario because, despite the high oil prices during 2007 to 2014 of that scenario, oil prices in the latter part of the projection period are much the same as the reference case.

In the greenhouse gas mitigation scenarios 1 and 2a-d, there is substantial uptake of HE-ICE vehicles. The share is higher the higher the carbon price. In scenario 2d where carbon prices are highest, HE-ICE vehicles dominate the vehicle market with a share of 93 percent by 2050. The high uptake of HE-ICE vehicles in the mitigation scenarios perhaps provides another explanation for the projected low uptake in alternative fuels at carbon prices of less than \$200/t CO_2e. That is, that it would appear more cost effective, under ESM assumptions, to reduce the impact of carbon prices by reducing fuel consumption via switching to a more efficient engine than via switching to less carbon intensive fuels.

[9] Coal to liquids is currently not examined by ESM nor is the option to couple either coal or gas to liquids diesel with carbon capture and storage. However, these are options which could be considered given Australia has significant coal resources and indications that there may be adequate carbon storage sites (Bradshaw et. al. 2002). Hydrogen could also be sourced from coal or gas, with or without carbon capture and storage.

Figure 12: Projected share of internal combustion engine (ICE) and hybrid electric-internal combustion engine (HE-ICE) vehicles in 2050



ESM's road transport projections need to be considered with some caution. ESM only considers fuel and engine technology choices on the basis of cost effectiveness and stock turnover constraints when in reality it is clear that such choices may also take into account many non-price related factors (e.g. colour, style, power and acceleration, comfort and safety). For example, ESM takes no account of the reduction in utility from a gas storage tank that reduces free cargo space in a passenger vehicle.

In considering cost effectiveness, ESM only considers the average vehicle in each mode driven for the average distance each year. In reality there are users who drive their vehicles significantly more than or less than the average annual kilometres and this significantly affects the importance of fuel costs in their overall budget. Also in reality there are a variety of vehicle sizes available for purchase which again affects each individual's degree of exposure to fuel prices.

ESM is also unable to capture the potential lags that might occur in bringing alternative fuel vehicles to the market. The uptake of CNG for example relies on the fact that fuel distribution facilities are in place and CNG vehicles are available for purchase or alternatively that sufficient retrofitting services are available. If alternative fuel vehicles are not brought to market quickly in the event of high oil prices, the only option for reducing exposure to oil prices in the short term may be to rely more heavily on fuels that are more readily adopted into the existing fleet such as petrol and diesel blends of ethanol and biodiesel or gas to liquids diesel.

Finally, ESM does not include fuel cell and electric vehicles. If fuel cell and electric vehicles were included and were cost effective (with or without carbon prices), in the scenarios examined here, the share of HE-ICE vehicles may be lower than was projected. Another implication if fuel cell or electric vehicles are cost effective would be that natural gas, hydrogen or even electricity from the grid could play an increasing role in road transport.

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