Measuring the contribution of a carbon price to greenhouse gas abatement in the context of strong complementary policies and low oil prices

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This paper examines the role of complementary policies and oil prices in determining the contribution of a carbon price to greenhouse gas abatement in the electricity and transport sectors in Australia. The inclusion in the reference case of the proposed expanded Mandatory Renewable Energy Target policy which requires a minimum 20 percent share of non-hydro renewable electricity generation by 2020 has the effect of reducing the projected abatement achieved by 2020 compared to the case where only a carbon price is introduced. The assumption of a low oil price path such as the United States Energy Information Administration's 2008 reference case projection decreases the projected greenhouse gas abatement achieved relative to the case where a carbon price is introduced in concert with a higher oil price path. The modelling results have implications for how modellers should construct their reference cases particularly when presenting abatement 'wedge' diagrams which require a reference case as a point of difference.

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Introduction

Many countries are considering or have already introduced a carbon price via a cap and trade system or direct taxation to reduce greenhouse gas emissions. Many countries are also considering or have already introduced policies that may be complementary in the sense that they contribute to greenhouse gas abatement although that may not have been the sole or original purpose of the policy. An example of this is Australia's expanded Mandatory Renewable Energy Target (MRET) which requires that electricity retailers purchase 20 percent of their electricity from non-hydro renewable sources by 2020. This proposed policy is an expansion of the existing MRET policy which required that a more modest 2 percent of additional non-hydro renewable electricity generation be purchased by 2010.

Events which are outside of the control of most governments could also increase the level of greenhouse gas abatement. A recent example is the international oil price which due to its considerable increase between 2004 and mid-2008 from around US$30/bbl to $US150/bbl[1]. This sustained increase in prices over 4 years raised expectations that abatement in the transport sector may become an easier task due to the additional price signal provided by the oil market for consumers and businesses to reduce oil consumption. Some governments do put in place policies such as subsidies which shield their population from international oil price signals. However, in Australia, oil product prices are generally a function of the international oil prices. The main exception to the generally unfettered market are that the Australian government places a 38 cents per litre tax on petrol and diesel fuel and lower rates on liquefied petroleum gas and natural gas to reflect their lower energy content. The government also selectively forgoes a portion of this fuel tax for off road diesel use predominantly in farming and mining and for urban buses and non-urban freight.

Economic modelling can provide some insights as to the relative effects of complimentary policies, carbon pricing and other price signals. Depending on the model structure and scenario design, economic models can project potential outcomes such as the carbon price associated with a given abatement level, the technologies deployed and the impact on activity levels and prices in each sector of the economy. This paper examines the implications of modelling which estimates the contribution of carbon prices to abatement of different sectors when examining scenarios with strong complementary policies and low oil prices.

Methodology

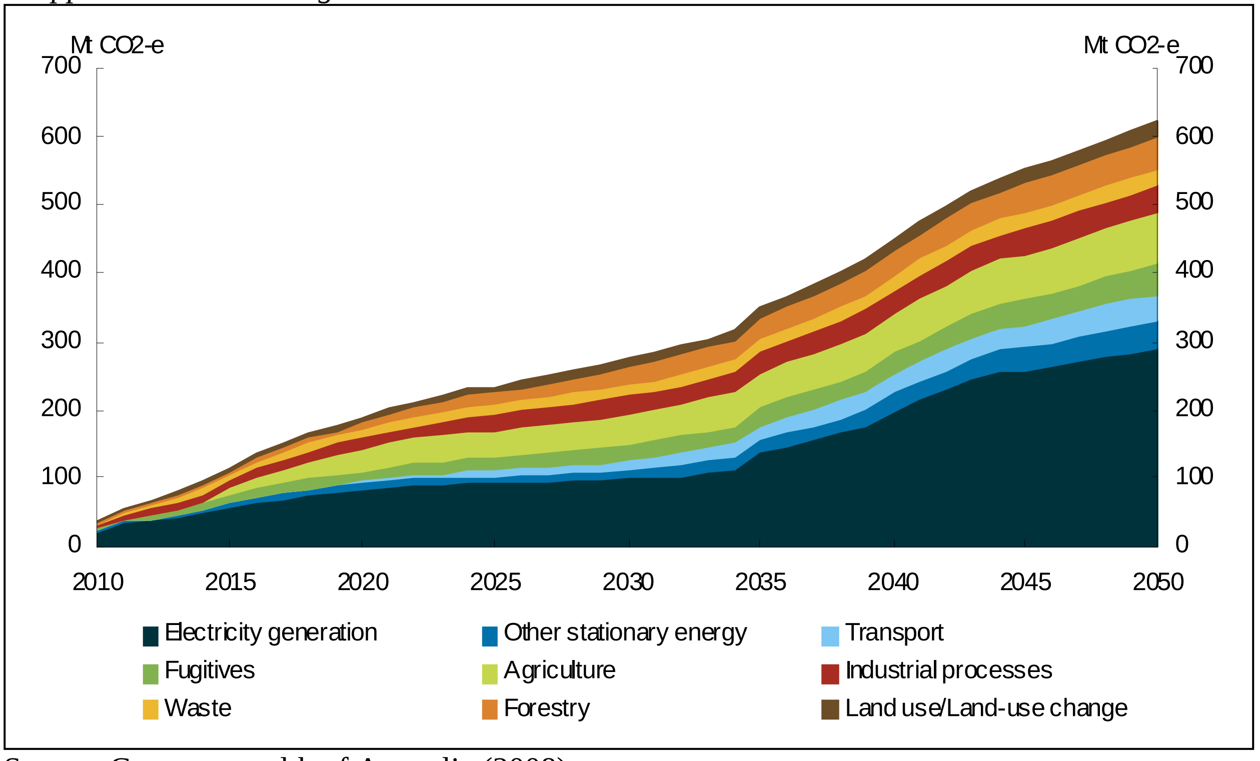
Of all the greenhouse gas intensive sectors, the modelling in this paper focuses on the contribution of the electricity and transport sectors to greenhouse gas abatement in Australia. Electricity and transport account for 35 and 14 percent of greenhouse gas emission in Australia respectively. This is almost half of all emissions. Australia has a higher share for electricity than the average share in the rest of the world due to the high share of coal in electricity generation

[1] Although the average for 2008 remained at around US$100/bbl due to the reduction in prices in the second half of 2008

and the relatively higher contribution of energy intensive metals manufacturing and mining industry to economic activity.

Whole of economy modelling by the Commonwealth of Australia (2008) confirms that the electricity and transport sectors will need to contribute almost a half of the total greenhouse gas abatement required in Australia by 2050 to contribute to achieving global stabilisation of greenhouse gases in the atmosphere of between 450 and 550ppm. Globally the share of abatement expected to be provided by the electricity and transport sectors is closer to 40 percent. Australian emission reductions in the agricultural sector, from fugitive emissions which are predominantly from coal mining, in industrial processes and in increased forestry are projected to make up the remaining share of required domestic abatement (Figure 1). Purchasing international carbon emission permits is also expected to contribute significantly, varying considerably - between 7 and 30 percent - depending on the stabilisation target.

Figure 1: Projected sources of domestic emissions reductions in Australia under a global 550ppm stabilisation target



Source: Commonwealth of Australia (2008)

Modelling framework

The framework employed in order to examine greenhouse gas abatement in the electricity and transport sectors is partial equilibrium modelling. This framework was chosen because it is relatively less resource intensive than general equilibrium modelling and because it offers the best opportunity to study the detailed technological implications of alternative scenarios.

Partial equilibrium models cannot directly model the economy wide impacts of the introduction of carbon prices. This limitation can be overcome via suitable integration with general equilibrium models and this type of framework has been applied in other studies (CSIRO and ABARE, 2006; BITRE and CSIRO, 2008). In this study the economy wide impacts have been exogenously imposed based on observing the economic impact of a given carbon price in these past studies. This introduces some inconsistency in the modelling results since the economy wide impacts are not recalibrated for each scenario. However, these errors are judged to be relatively small.

The partial equilibrium model employed is called the Energy Sector Model (ESM).

Description of ESM

ESM is an Australian energy sector model co-developed by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the Australian Bureau of Agricultural and Resource Economics (ABARE) in 2006. ESM is solved as a linear program where the objective function is to maximise welfare which is the discounted sum of consumer and producer surplus over time. The sum of consumer and producer surplus is calculated as the integral of the demand functions minus the integral of the supply functions which are both disaggregated into many components across the electricity and transport markets. The objective function is maximised subject to constraints that control for the physical limitations of fuel resources, the stock of electricity plant and vehicles, and various market and technology specific constraints such as the need to maintain a minimum number of peaking plants to meet rapid changes in the electricity load.

ESM is specifically designed to examine long term investment decision making and technological change. It has a detailed technology representation. The features of ESM include:

- Coverage of all States and the Northern Territory (Australian Capital Territory is modelled as part of New South Wales);
- Trade in electricity between National Electricity Market (NEM) States;
- Nine road transport modes: light, medium and heavy passenger cars; light, medium and heavy commercial vehicles; rigid trucks; articulated trucks and buses;
- Twelve road transport fuels: petrol; diesel; liquefied petroleum gas (LPG); natural gas (compressed (CNG) or liquefied (LNG)); petrol with 10 percent ethanol blend; diesel with 20 percent biodiesel blend; ethanol and biodiesel at high concentrations; gas to liquids (GTL) diesel; coal to liquids (CTL) diesel with upstream CO_2 capture; hydrogen (from renewables) and electricity;
- Rail, air and shipping sectors are governed by much less detailed fuel substitution possibilities;
- Four engine types: internal combustion; hybrid electric/internal combustion; hybrid plug-in electric/internal combustion and fully electric;
- Seventeen centralised generation (CG) electricity plant types: black coal pulverised fuel; black coal integrated gasification combined cycle (IGCC); black coal with partial CO_2 capture and sequestration (CCS) (50 per cent capture rate); black coal with full CCS (85 per cent capture rate); brown coal pulverised fuel; brown coal IGCC; brown coal with partial CCS (50 per cent capture rate); brown coal with full CCS (85 percent capture

rate); natural gas combined cycle; natural gas peaking plant; natural gas with full CCS (85 per cent capture rate); biomass; hydro; wind; solar thermal; hot fractured rocks (geothermal) and nuclear;

- Fourteen distributed generation (DG) electricity plant types: internal combustion diesel; internal combustion gas; gas turbine; gas micro turbine; gas combined heat and power (CHP); biomass CHP; gas micro turbine CHP; gas reciprocating engine CHP; solar photovoltaic; biomass; wind; biogas reciprocating engine; natural gas fuel cell and hydrogen fuel cell;
- All vehicles and centralised electricity generation plants are assigned a vintage based on when they were first purchased or installed in annual increments;
- Four electricity end use sectors: industrial; commercial and services; rural and residential
- Time is represented in annual frequency (2006, 2007, …, 2050).

Greater detail on the parameter values assigned in the model and some further discussion for why this technology aggregation was chosen is provided in previous applications of ESM such as Graham et al. (2008).

ESM assesses technologies on the basis of their relative costs subject to constraints such as the turnover of capital stock and existing or new policies such as subsidies and taxes. The model aims to mirror real world investment decisions by simultaneously taking into account:

- The requirement to earn a reasonable return on investment over the life of a plant or vehicle;
- That the actions of one investor or user affects the financial viability of all other investors or users simultaneously and dynamically;
- That consumers react to price signals;
- That the consumption of energy resources by one user affects the price and availability of that resource for other users, and the overall cost of energy and transport services; and
- Energy and transport market policies and regulations.

ESM does not directly take into account issues such as community acceptance of technologies but these can be controlled by imposing various scenario assumptions which constrain the solution to user imposed limits. For example, we impose changes in preferences for vehicle sizes over time.

Scenarios

The central scenario in this study is a projection of Australian greenhouse gas abatement under a carbon price introduced in 2010. The carbon price path applied in the modelling is based on the CPRS-5 scenario which was proposed and examined in Commonwealth of Australia (2008)[2].The CPRS-5 scenario has been estimated to deliver a 5 percent reduction in Australian greenhouse gas emissions below 2000 levels in 2020 and a 60 reduction below 2000 levels by 2050. It has

[2] CPRS stands for Carbon Pollution Reduction Scheme which is the name given to the scheme introducing emission trading in Australia

been designed to be consistent with achieving stabilisation at a global 550ppm greenhouse gas concentration and includes assumptions with regard to sharing of the emission reduction burden between countries. The CPRS-5 scenario was chosen because it is the least ambitious and consequently enjoys the widest political support in Australia. However, it is possible that a more ambitious target and consequently a higher carbon price may be supported in the future. Under the CPRS-5 scenario the carbon emission permit price rises from approximately $A20/t$CO_2$e in 2010 at a fairly constant rate of 4 per cent per annum to $A100/t$CO_2$e in 2050. The fairly smooth price for carbon emission permits is attributed to the expected inclusion of banking and borrowing arrangements in the emission trading scheme. Nevertheless some volatility can be expected in reality.

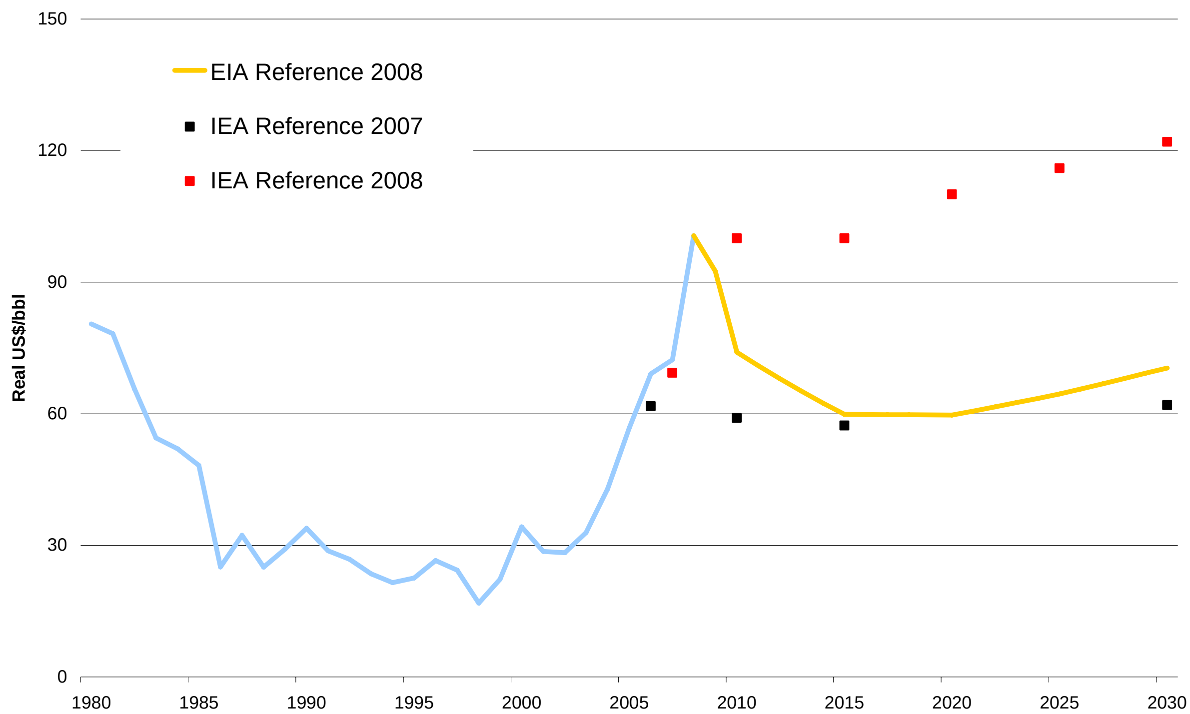
The Mandatory Renewable Energy Target is considered an important complementary policy to the emission trading scheme. It is implemented via a constraint on the minimum amount of non-hydro renewable power generation such that it reaches 45 terawatt hours (TWh) by 2020. Together with an expected 15 TWh of existing renewable power, mostly from hydro, this contributes 20 percent of the 300 TWh of expected electricity generation demand in 2020. The policy is based on a required amount of TWhs rather than the 20 percent share so the final share may be slightly different in reality. This is a very strong complementary policy and so we construct an alternative scenario to examine how this impacts on the technology mix and overall level of abatement. This is achieved by removing the minimum renewable electricity generation production constraint in ESM.

At the time that Commonwealth of Australia (2008) conducted its study into greenhouse gas abatement in Australia it assumed a world oil price that closely matched the Energy Information Administration's *Annual Energy Outlook 2008*. This was the most recent international projection available at the time and was preferable to the International Energy Agency's 2007 projection (see Figure 2) which, on the basis of oil prices being experienced in 2008, appeared to be well below expectations. However, the International Energy Agency later released their *World Energy Outlook 2008* which updated its projection with real oil prices of US$30 to US$60/bbl higher than its previous outlook. An increase in the level of oil prices can be expected to have significant impact on the contribution of transport to greenhouse gas abatement, providing an additional incentive over and above the carbon price for consumers to reduce their consumption of fossil fuels for transport.

Given the significant change in outlook for world oil prices, the IEA (2008) oil price projection is explored as an alternative oil price scenario. The expectation is that this will deliver much greater greenhouse gas abatement in the transport sector than under the EIA (2008) oil price.

To summarise, two alternative scenarios are explored maintaining the same carbon price path. However one scenario removes the proposed expanded MRET policy and the other significantly increases the oil price to bring it up to date with more recent forecasts.

Figure 2: Historical and projected real world oil prices



Source: EIA (2008), IEA (2007), IEA (2008)

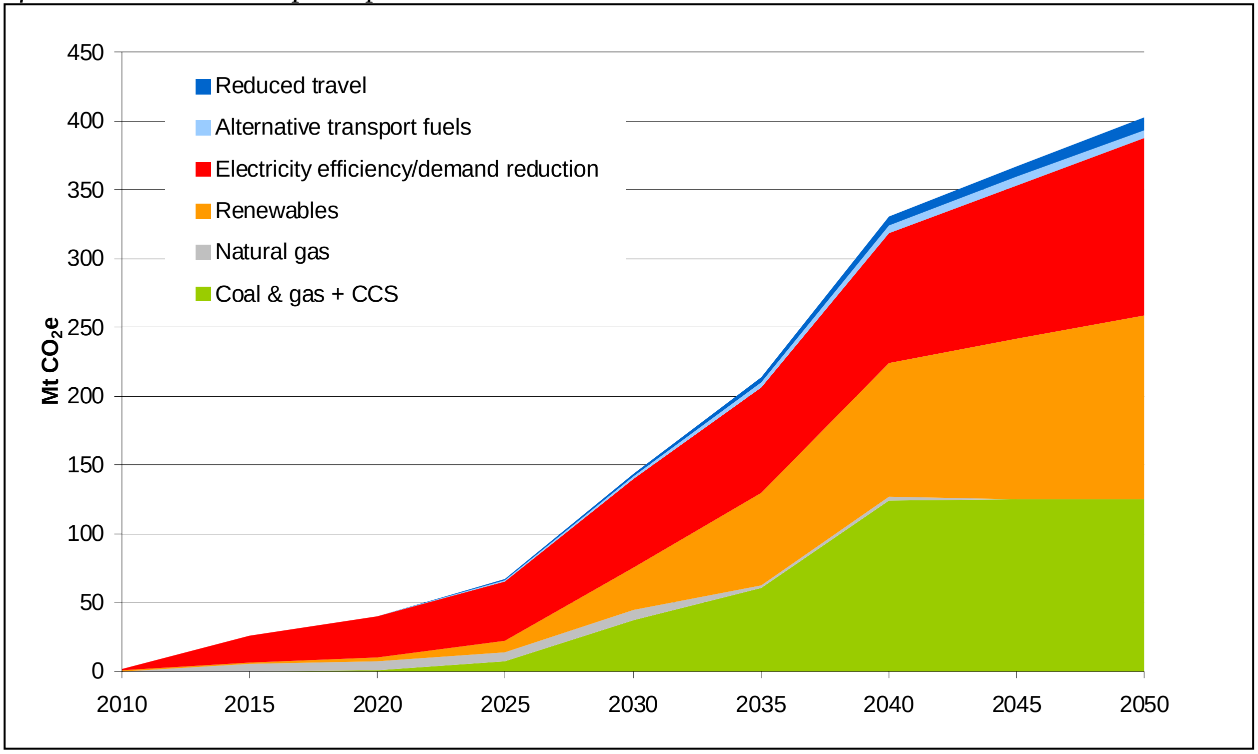
Modelling results

'Wedge' diagrams are a commonly employed framework for graphically illustrating the contribution of different sectors, policies or technologies to greenhouse gas abatement. They show the reduction in greenhouse gas emissions relative to a reference case by each contributing sector. The reference case typically includes all current and expected events and policies other than the introduction of a carbon price. In such cases the 'wedge' diagram represents the abatement achieved only by the carbon price, not any complementary policies or independent processes. It does include, however, co-dependent abatement enhancing processes such as induced technological change and changes in consumer tastes and preferences assuming such processes have been included in the modelling framework. In ESM, faster rates of technological improvement and increasing preferences for smaller vehicles and public transport are exogenously imposed on the model. These changes are assumed to be a function of the carbon price and are greatly strengthened relative to the reference case and increase the greater the level of the carbon price.

Figure 3 shows the greenhouse gas abatement achieved by the electricity and transport sectors under the CPRS-5 carbon price path. Commonwealth of Australia (2008) projected that under these assumptions, electricity and transport would contribute approximately 325 $MtCO_2e$ of abatement by 2050. The ESM modelling results are mostly in accordance with this result with some variation. Electricity sector abatement is projected to deliver 388 $MtCO_2e$ by 2050. There are two reasons why this projection is higher than the previous study, one is that ESM includes upstream fugitive emissions from coal mining and gas extraction and transport in the electricity sector. Consequently some of the expected 44 MtCO_2e of abatement in this sector is counted in the electricity sector. The second reason for the higher expected level of electricity sector abatement is that some electricity generation technologies in ESM are assumed to be lower cost.

ESM projects transport sector abatement to be less than was project in Commonwealth of Australia (2008). This difference is directly due to an upward revision in the expected costs of plug-in hybrid vehicles reducing the amount of transport sector abatement achieved by 18 MtCO_2e. All other assumptions are identical.

Figure 3: Greenhouse gas abatement in the Australian electricity and transport sector as a result of the CPRS-5 carbon price path



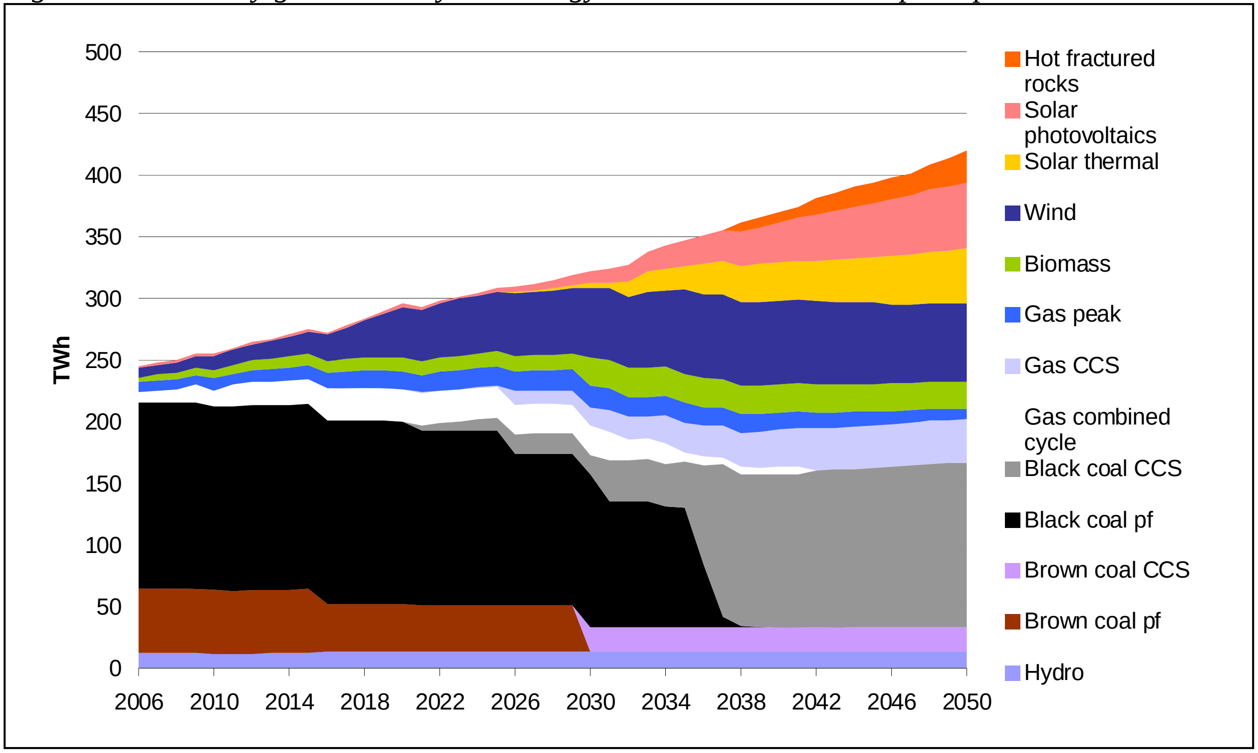
These results emphasise that the electricity sector makes a disproportionately higher contribution to abatement then its current share of emissions (35 percent) and conversely transport makes a disproportionately lower contribution to emission abatement compared to its current contribution (14 percent). This observation has been previously noted in Graham et al (2008). It is a result of the higher carbon content per unit of energy in delivered Australian electricity compared to petrol or diesel and the lower share of transport fuel in the total delivered cost of transport services (travel in kilometres) relative to the share of fuel costs in delivered electricity. There are also fewer options available in the short term for reducing emissions from transport relative to the electricity sector. The options are particularly limited in long distance transport.

Greenhouse gas abatement in the electricity sector is achieved via a combination of reduced demand, switching from coal to natural gas and greater use of renewables and utilisation of CO_2 capture and storage (CCS) in coal and gas fired electricity generation. The uptake of renewables prior to 2020 is a small component of electricity sector abatement during that time since the Mandatory Renewable Energy Target policy was included in the reference case.

However the contribution of renewables increases steadily throughout the period to 2050 due to the combination of the MRET policy and the increasing carbon price (Figure 4). In the period to 2020 when the MRET policy is in force, wind power and to a much lesser extent solar photovoltaic technology are taken up together delivering the required additional 45 TWh of electricity generation. Wind power is the lowest cost renewable wholesale power generator throughout this period with most other renewable energy technologies still in the development and demonstrations stages. However solar photovoltaics is expected to be mature and competitive in roof top applications in the commercial and residential retail markets. Of the non-renewables, natural gas electricity generation dominates new power plant investment in the first decade from the commencement of emission trading in 2010. The moderate emission intensity of gas fired electricity means that it is lower cost than coal fired power without CCS.

In the post 2020 period solar thermal electricity generation is expected to be among the next set of technologies to emerge as economically viable emission abatement technologies. Solar thermal power is expected to be in the form of high temperature concentrating towers. Solar technologies can be expected to receive a premium relative to the average daily electricity price because their output is confined to the daylight hours when prices are higher.

Figure 4: Electricity generation by technology under CPRS-5 carbon price path



Hot fractured rocks and coal with CCS are also expected to be economically viable in the long term. CCS can be retrofitted or built into new plant so it uptake could be rapid once the technology is commercially available.

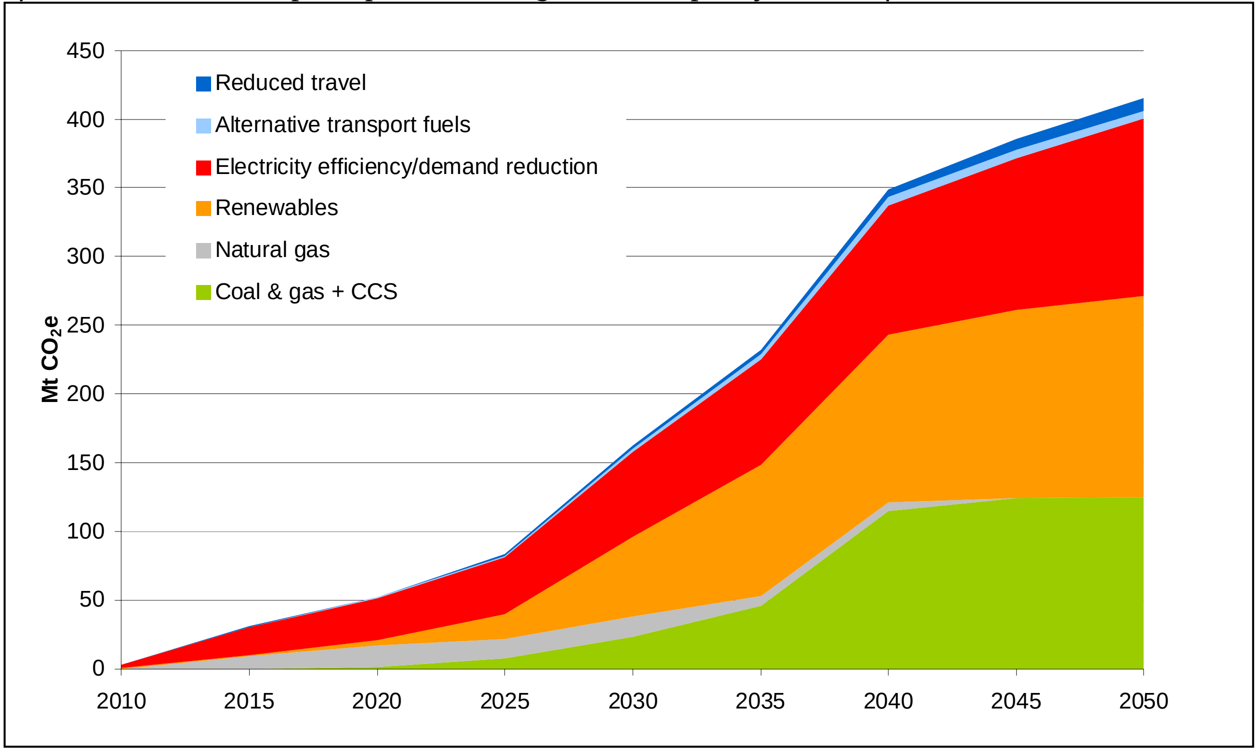
Conventional natural gas (without CCS) cannot compete much beyond around 2030 since its emissions per megawatt hour, while comparatively moderate by current standards, are too high relative to other technologies deployed during this time. There could be some uptake of natural gas power with CCS. However, this is high cost and would normally only be taken up in preference to coal with CCS once carbon prices are high and where the region has no coal resources and it's remaining renewable resources are constrained.

Impact of MRET policy

Figure 5 shows how the greenhouse gas abatement projected in ESM is changed when we change the reference case and carbon price scenario assumption that the expanded MRET policy is introduced. When the MRET is not included in the reference case the carbon price is projected to deliver around 30 percent more abatement during the period to 2020. This is because the reference case emissions are higher with no MRET policy with only 7 percent non-hydro renewables compared to the 20 percent that is required when the MRET scheme is in place.

The total level of emission reduction for the scenario with the MRET policy in place is 16 $MtCO_2e$ in 2020 compared to the scenario where it is not (Figure 9). However, by 2050 there is no significant difference in the emission level. This is a result of the modelling framework which does not include endogenous technological change. It is possible that in reality early uptake of renewable electricity generation in Australia could induce technological learning that lowers its cost, leading to greater abatement in the long term. However, this effect may only be small since the volume of deployment in Australia may not be large enough to move the technologies significantly further down the notional global learning curve. A globally coordinated accelerated deployment policy would have greater impact on costs. Deployment induced learning in Australia will be highest in those technologies which are at infant stages (such as geothermal hot fractured rocks) or where there is significant learning in local installation of global technologies. Installation costs can amount to up to a fifth of total long run marginal costs.

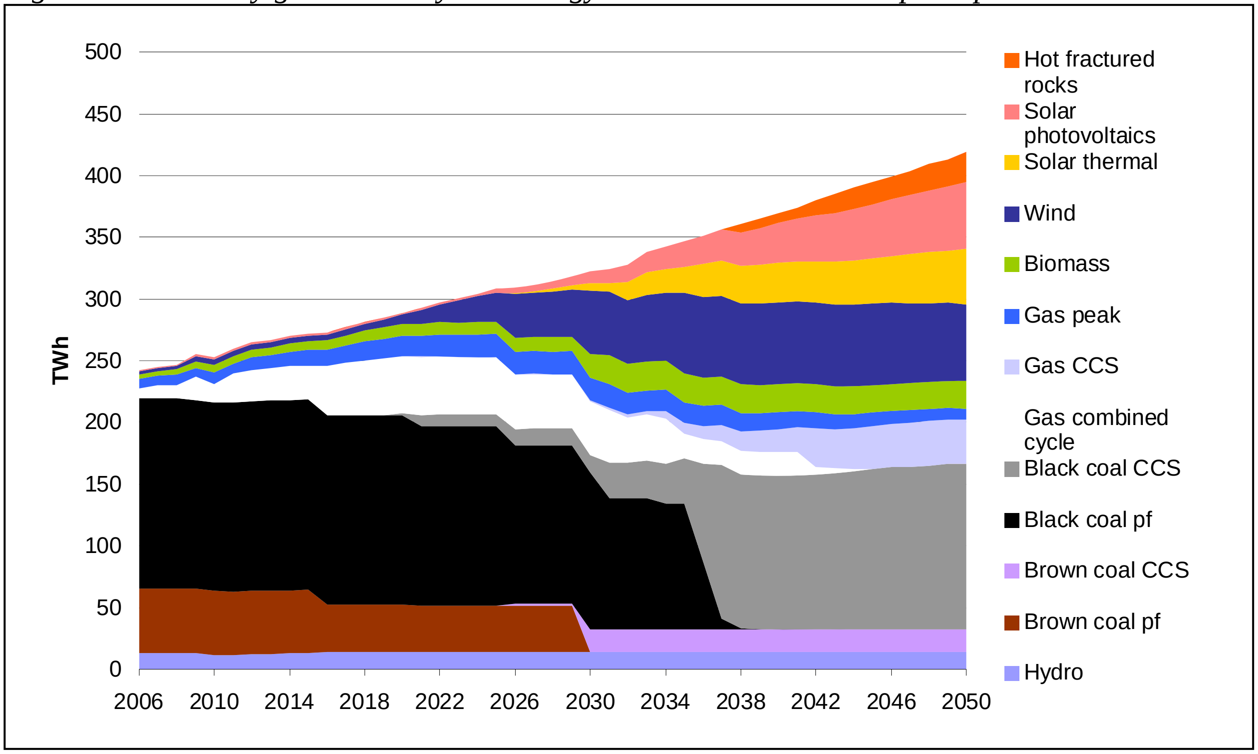
Figure 5: *Greenhouse gas abatement in the Australian electricity and transport sector as a result of the CPRS-5 carbon price path assuming no MRET policy in the reference case*



Despite the uncertain long term benefits there is little doubt that the MRET contributes to accelerated greenhouse gas abatement in the short term. When the MRET policy is not in place the preference for investor will be to install natural gas combined cycle power stations instead of renewable electricity generation plants (Figure 6). By 2020, natural gas combined cycle power plants are expected to achieve a market share of 19 percent compared to only 11 percent when the MRET policy is in place.

Natural gas combined cycle power plants are projected to remain the lowest cost power generation option until around 2020 when coal plants that include CCS become available. At that point the long run marginal costs of coal with CCS will be higher than gas combined cycle power plants at the prevailing carbon price. However, it will only take a few years for the carbon price to switch the relative competitiveness. As such coal with CCS is more likely to be able to provide an adequate return on investment over the 30 years to 2050. To illustrate this point, all natural gas combined cycle power plants with CCS are projected to be closed or retrofitted with CCS by 2045.

Figure 6: Electricity generation by technology under CPRS-5 carbon price path

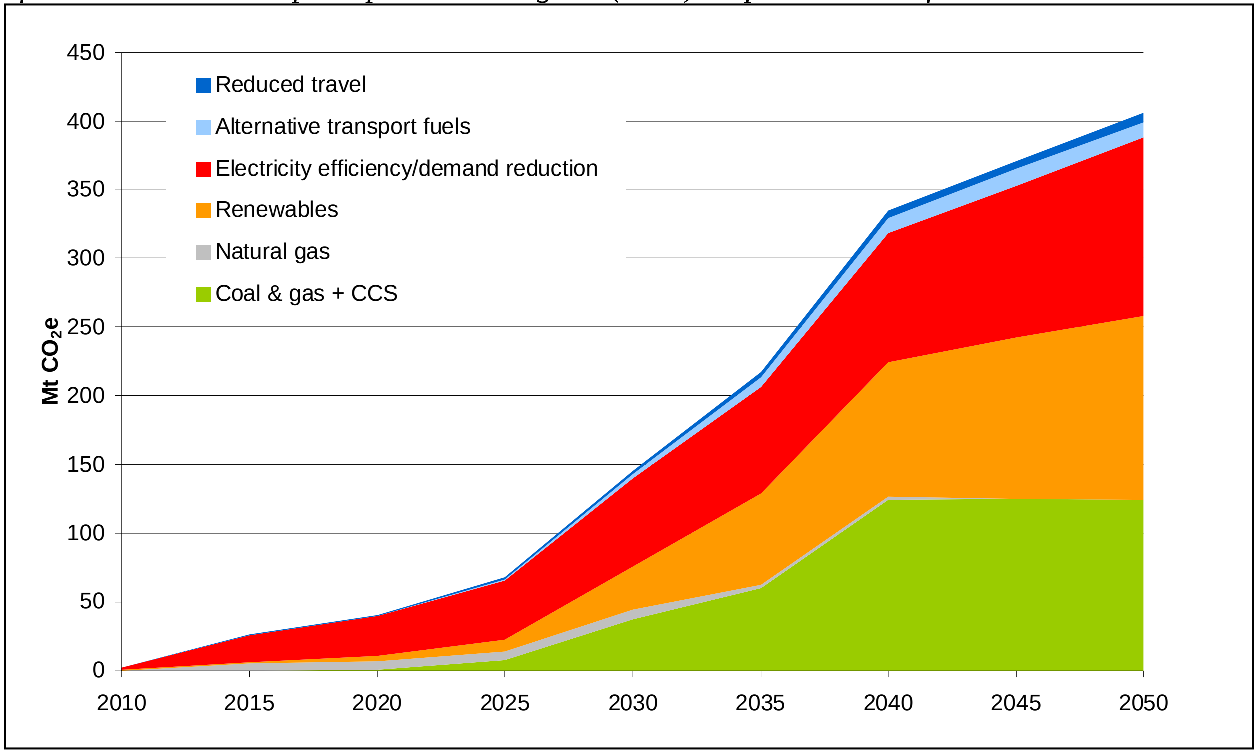


Impact of alternative oil price

When the latest IEA (2008) oil price outlook is included in the carbon price scenario and reference case the amount of greenhouse gas abatement achieved by the carbon price in the transport sector is increased by 25 percent. Unlike the MRET policy, the additional abatement incentive provided by the higher oil price is sustained throughout the projection period because the higher prices remain (whereas the MRET policy concluded in 2020). The US$20-$50/bbl increase in the oil price outlook, relative to EIA (2008), has the equivalent effect on petrol and diesel transport fuel prices of increasing the carbon price in each year by around A$100-200/t$CO_2$e.

In absolute terms the overall level of emissions in both the electricity and transport sector is 7 percent lower in 2020 and 33 percent lower in 2050 (Figure 9). The change in total electricity and transport emissions increases over time because the transport sector is an increasingly larger portion of the remaining emissions in both sectors over time. That is, the electricity sector decarbonizes faster than the transport sector in all scenarios.

Figure 7: *Greenhouse gas abatement in the Australian electricity and transport sector as a result of the CPRS-5 carbon price path assuming IEA(2008) oil price in the reference case*



The higher oil prices associated with IEA (2008) induce a wide range of fuel and vehicle technologies to be taken up (Figure 8). For long distance trucking ESM projects greater use of liquefied natural gas which is available at a lower cost per gigajoule than diesel in Australia since domestic pipeline distributed gas is not yet driven by international oil and gas prices and is expected to continue to command a discount to the export liquefied natural gas (LNG) price due to the lower infrastructure costs of pipelines compared to LNG export.

Another significant change in the technology mix is the increase in the number of fully electric and plug-in hybrid electric vehicles which increases from 15 percent under EIA (2008) oil prices to 36 percent under IEA (2008) oil prices by 2050. More minor changes are an increase in diesel use reflecting the higher efficiency of diesel internal combustion engines. Biofuel uptake is also increased by 2050. This uptake could have been higher. However, ESM assumes this resource is constrained to be high cost above around 10 percent of Australian fuel consumption based on analysis of available biomass feedstocks (Graham et al., 2008). The availability of new biofuel production technologies and feedstocks could expand the potential availability of competitively priced biofuels, significantly increasing the potential greenhouse gas reduction in transport.

Figure 8: *Projected uptake of alternative fuels and vehicles by 2050 under two different oil price assumptions*

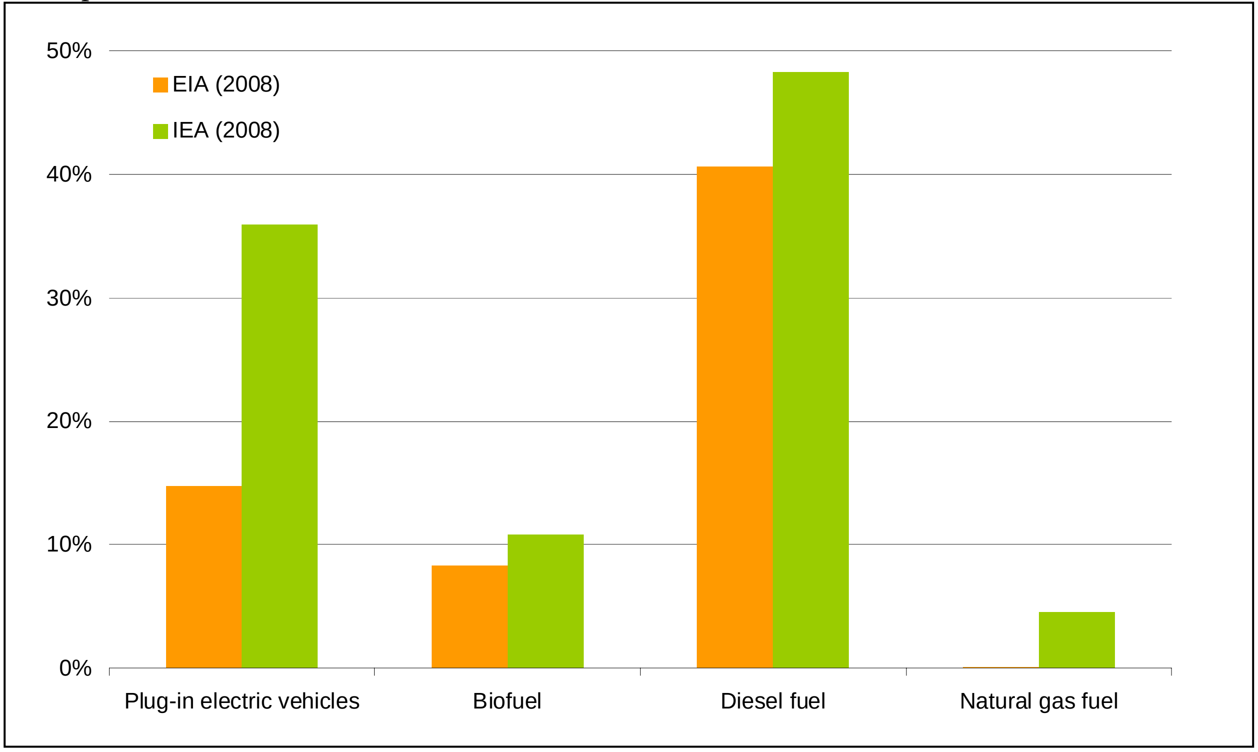
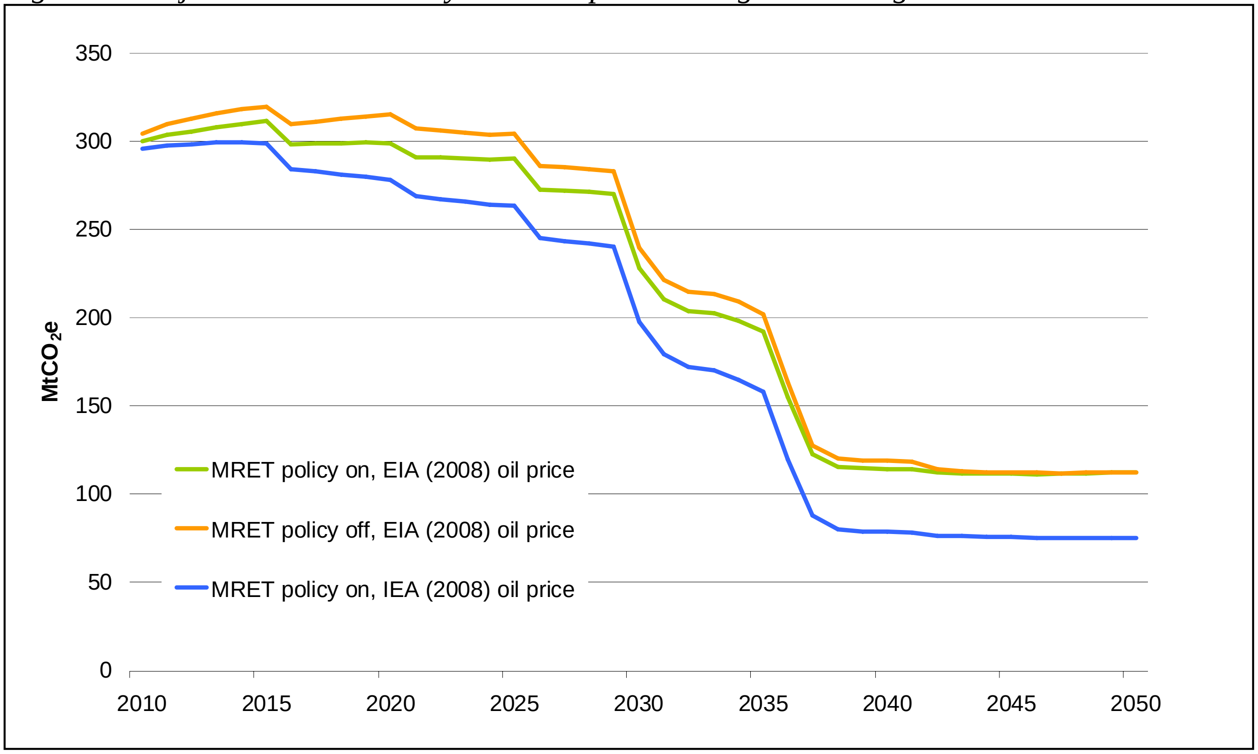


Figure 9: Projected total electricity and transport sector greenhouse gas emissions to 2050



Conclusions and implications

This paper has examined the role of complementary policies and oil prices in determining the contribution of a carbon price to greenhouse gas abatement in the electricity and transport sectors in Australia. The inclusion of the proposed expanded MRET policy which imposes a lower bound on the share of non-hydro renewable electricity generation by 2020 has the effect of reducing the projected abatement achieved by 2020 compared to the case where only a carbon price is introduced. This is because the MRET scheme significantly lowers reference case electricity sector emissions, by diverting investment away from natural gas fired electricity generation plant.

The assumption of a low oil price path such as the EIA (2008) reference case projections decreases the projected greenhouse gas abatement achieved relative to the case where a carbon price is introduced in concert with a higher oil price path. Inclusion of the higher oil price path in an emission trading scenario leads to substantially lower Australian greenhouse gas emission levels relative to a low oil price emission trading scenario – a difference of 37 $MtCO_2e$. However, relative to its own reference case the effect is less dramatic since much of the projected abatement also occurs in the reference case – a difference of 18 $MtCO_2e$.

Overall the impact of the oil price had the greatest change on the level of emissions, calculated to be equivalent to the impact of increasing the assumed carbon price in the transport sector by a factor of between two to five, decreasing emission levels by one third by 2050. However, the MRET policy can be expected to accelerate the uptake of renewable electricity generation technologies and its long term impact could not be fully assessed in this modelling framework because it did not include a methodology for calculating deployment induced technological change. This is one possible avenue for further research and would need to consider the contribution of Australia in international technology development.

The modelling results have implications for how modellers should construct their reference cases particularly when presenting abatement 'wedge' diagrams which require a reference case as a point of difference. There is significant potential to mislead audiences who are not familiar with interpreting such diagrams. Careful attention must be given to constructing and communicating the assumptions within the reference case. It is also important that results be presented both as differences and as levels in order to fully appreciate the significance of any differences observed.

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