Paper presented at the Australian Agricultural and Resource Economics Society (AARES) 52nd Annual Conference, Canberra, 6 February 2008.

Title: "Emissions Trading and the Convergence of the Australian Electricity and Transport Markets"

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Keywords: Energy; Emissions trading; Electricity and transport; integrated modelling

Abstract:
Bottom up partial equilibrium modelling of the energy sector has tended to focus on the electricity sector given its typically large share of total emissions, the deregulation of that market in many countries and the relatively well understood technology options. In contrast, this paper employs a model of the energy sector to investigate the proportion electricity and transport may contribute given the relative cost of abatement in those sectors, for specified emission targets. A related issue is the potential convergence of the two sectors through greater uptake of electrically powered transport.

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Emissions Trading and the Convergence of the Australian Electricity and Transport Markets

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1. Introduction

In the absence of new measures, continued growth in energy demand is projected to lead to national emissions rising to 127 percent of 1990 levels by 2020. This growth will be driven primarily by the stationary energy sector, where emissions in 2020 are projected to be 84 percent higher than 1990 levels (Prime Ministerial Task Group on Emissions Trading, 2007).

Despite the large share of GHG emissions attributable to the stationary energy sector, it is generally accepted that an emissions trading scheme (ETS) that has universal coverage of all economic sectors, is best placed to locate lowest cost abatement opportunities. The recent report from the Prime Ministerial Task Group on Emissions Trading endorsed this principle, but recommended that measurement uncertainties and compliance cost issues meant that agricultural and land use emissions be initially excluded from an ETS. Similarly, the National Emissions Trading Taskforce (NETT) recently expanded its terms of reference to consider an economy-wide scheme beyond its original scope of the stationary energy sector (NETT, 2007).

To determine the extent of least cost abatement opportunities in the energy sector, this paper employs a model of the energy sector to investigate the proportion electricity and transport may contribute given the relative cost of abatement in those sectors, for specified emission targets. A related issue is the potential convergence of the two sectors through greater uptake of electrically powered transport in the form of electric vehicles (EVs) and plug-in hybrid vehicles (PHEVs).

This paper proceeds as follows. Section 2 outlines the partial equilibrium model used in this paper. Section 3 formulates our three emission reduction scenarios based on the information contained in the recent fourth assessment report of the IPCC and contemporary debate in Australia. Section 4 briefly discusses the key assumptions impacting on the modelling results. Section 5 discusses the modelling results and Section 6 concludes.

2. Outline of economic modelling approach

Economic modeling of energy policy issues is often discussed in the literature as being either 'top-down' or 'bottom-up' (see Hourcade *et al*., 2006 for a recent review of the literature). Top-down models provide a comprehensive representation of the operation of all sectors of the economy from either the global, national or regional viewpoint. Regardless of viewpoint, bottom-up models tend to only model particular sectors of the economy, such as the energy sector, but do so in considerable detail. Bottom-up models more accurately describe and discriminate between the characteristics of the technologies and processes associated with the operation of energy markets.

As this paper is concerned with technological choices and the potential for convergence between electricity and transport sectors, a bottom-up modelling approach is deemed appropriate.

ESM (Energy Sector Model) is an Australian energy sector model co-developed by CSIRO and the Australian Bureau of Agricultural and Resource Economics (ABARE) as a scenario analysis tool. ESM is a partial equilibrium (bottom-up) model of the electricity and transport sectors solved as a linear program. The model has a robust economic decision making framework around the cost of alternative fuels and vehicles as well as detailed fuel and vehicle technical performance characterisation such as fuel efficiencies and emission factors by transport mode, vehicle type, engine type and age. It also has a detailed representation of the electricity generation sector. Competition for resources between the two sectors and relative costs of abatement are resolved simultaneously within the model.

The main features of ESM used in this report include:

- Coverage of all States and Territories;
- 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), compressed natural gas (CNG), petrol with 10% ethanol blend, diesel with 20% biodiesel blend, ethanol and biodiesel at high concentrations, gas to liquids diesel, coal to liquids diesel, 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 electric plug-in/internal combustion and fully electric;
- Seventeen centralised generation (CG) electricity plant types (black coal pf, black coal IGCC, black coal with partial CCS (50 percent capture rate), black coal with full CCS (85 percent capture rate), brown coal pf, brown coal IGCC, brown coal with partial CCS (50 percent 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 percent capture rate), biomass, hydro, wind, solar thermal, hot fractured rocks, 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 PV, 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; and

- Time is represented in annual frequency (2006, 2007, …, 2050).

All technologies are 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 (or input) variables that define the economic environment, the ESM model determines the time paths of the endogenous (output) variables. Key output variables include:

- Fuel, engine and electricity generation technology uptake;
- Primary and final fuel consumption;
- Cost of transport services (e.g. c/km);
- Price of fuels;
- Greenhouse gas and criteria air pollutant emissions;
- CO_2 permit prices; and
- Demand for transport and electricity services.

Some of these outputs can also be defined as fixed inputs depending upon the design of the scenario.

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.

The model utilises linear programming techniques 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.

The model evaluates uptake on the basis of cost effectiveness but at the same time takes into account the key constraints with regard to the operation of energy and transport markets, current excise and mandated fuel mix legislation, greenhouse gas emission limits, existing plant and vehicle stock in each State, and lead times in availability of new vehicles or plant. It does not take into account issues such as community acceptance of technologies but these can be controlled by user inputs.

3. Scenario description

Contemporary debate on emissions trading in Australia has shifted substantially in recent times. The recently installed Federal Government has an aspirational goal to reduce emissions by 60 percent on 2000 levels by 2050 but has not committed to a legislated emission target prior to the report of the Garnaut Review. This aspirational goal is consistent with a global agreement to achieve 450 ppmv where all countries have the same target or a global target of 550 ppmv where developed countries (Annex 1) have a differentiated (deeper) target which allows developing countries (Non-Annex 1) to have a less stringent GHG abatement task.

However, the recent fourth assessment report of the Intergovernmental Panel on Climate Change (IPCC) posits that more stringent emission reduction targets are required to limit the chance of exceeding 2°C increase in global mean temperatures. It noted that: "Using the 'best estimate' assumption of climate sensitivity, the most stringent scenarios (stabilizing at 445–490 ppmv CO_2-equivalent) could limit global mean temperature increases to 2–2.4°C above the pre-industrial level, at equilibrium, requiring emissions to peak before 2015 and to be around 50% of current levels by 2050" (Fisher *et al*., 2007: 173). This implies that: "developed countries as a group would need to reduce their emissions to below 1990 levels in 2020 (on the order of –10% to 40% below 1990 levels …) and to still lower levels by 2050 (40% to 95% below 1990 levels), even if developing countries make substantial reductions" (Gupta *et al*., 2007: 775).

The position that developed countries may need to reduce emissions at a greater rate in the medium-term is a departure from the straight-line reduction path that is typically modelled in emission reduction scenarios. Examples of the straight-line approach in the Australian context include the Business Roundtable on Climate Change examining 60 percent below 2000 levels by 2050 (Allen Consulting, 2006) preceded by earlier studies that adopted 60 percent below "current" levels by 2050 (e.g., Australian Climate Group, 2004; Turton *et al*., 2002).

Debate on the proposed timing of global emissions trading is still on-going, however it is increasingly recognised that "early action" is preferential to "delayed action" to limit the chance of exceeding 2°C increase in global mean temperatures. This is consistent with economic analysis that delay in taking action on climate change would make it necessary to accept more climate change (greater probability of exceeding 2°C), and, eventually lead to higher mitigation costs (e.g., Stern *et al*., 2006; Allen Consulting, 2006; Energy Futures Forum, 2006). In the Australian context, the NETT and the Prime Ministerial Task Group on Emissions Trading have endorsed this principle, recommending that Australia commence emissions trading in 2010 with the first emission reduction target set in 2011.

Given the state of the current debate summarised above we will examine three emission mitigation scenarios (EMS) for the Australian energy sector:

- a smooth trajectory to 60% below 1990 emission levels by 2050 (**EMS1990-60**);

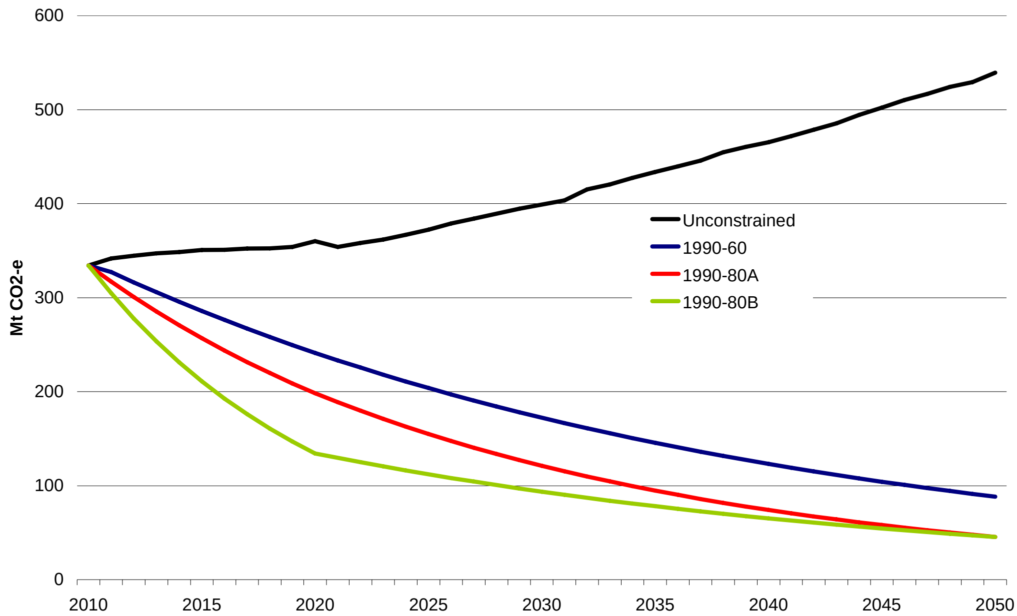
- a reduction path to 10% below 1990 levels by 2020 and smooth path to 80% below 1990 levels by 2050 (**EMS1990-80A**); and

- a reduction path to 40% below 1990 levels by 2020 and smooth path to 80% below 1990 levels by 2050 (**EMS1990-80B**).

Figure 1 shows the GHG emission reduction paths for the combined electricity and transport sector.[2] ESM projects combined electricity and transport sector GHG emissions to be approximately 326 million tonnes (Mt) in 2010 at the commencement of carbon trading. This estimate is higher than recent analysis released by the AGO (2006a,b) that projects emissions of 295 Mt CO_2e in 2010 and largely reflects our use of full fuel cycle GHG emission factors.

All three EMS represent significant amounts of abatement. In the absence of emissions trading, ESM projects combined electricity and transport sector GHG emissions to be approximately 540 Mt in 2050. GHG emissions under the EMS1990-60 scenario are projected to decline to around 88 Mt by 2050, constituting approximately 452 Mt of abatement. Emissions are presumed to decline at a constant rate in EMS1990-60. In contrast, both EMS1990-80A and EMS1990-80B have targets of around 45 Mt by 2050, via different emission reduction paths.

Figure 1 GHG emission reduction paths for the combined electricity and transport sector

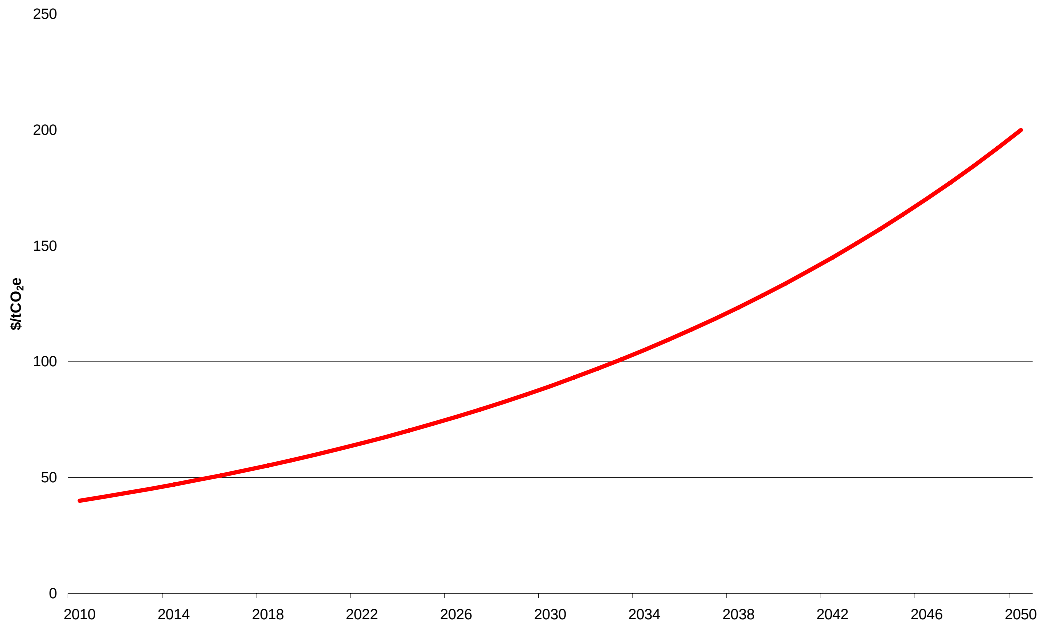


As discussed in Section 2, ESM does not contain a detailed representation of the non-road transport sector (e.g., rail, air and sea). Although the road transport task currently accounts for 90 percent of transport sector emissions, it is expected that the share of emissions from domestic and international air travel will increase in the future (AGO, 2006b). Accordingly, the analysis is this paper does not assess the abatement potential of the non-road sector.

[2] ESM does not contain a representation of the stationary energy outside of the electricity generation sector.

A flaw in our approach is that, in reality, the movements in the CO_2 permit price will be determined by the cost of abatement available in other sectors, including the purchase of international credits. The assumed cost of abatement from other sectors begins at around $50 per tonne of CO_2 in 2010 and increases at a constant percentage rate to $200 per tonne of CO_2 in 2050, consistent with approximately mid range estimates of carbon prices reviewed by the Intergovernmental Panel on Climate Change (see Fisher *et al*., 2007). The cost of abatement from other sectors in shown in Figure 2.

Figure 2 Price of CO_2 abatement in other sectors



Source: Hatfield-Dodds *et al*. (2007)

Another important issue in the design of an emissions trading scheme is the extent to which existing relatively high emission intensive assets may be quarantined from a CO_2 penalty for the purposes of compensation or other equity considerations. The modelling in this report assumes that no grandfathering of emissions takes place and all GHG emiting generators' must bid for permits.

4. Key assumptions

Given our use of a 'bottom-up' energy sector model, there are a number of assumptions underpinning the modelling reported in this paper. The following list briefly identifies the key assumptions:

- **Oil prices:** we use the projections from the Energy Information Administration (EIA) 'reference oil price' scenario that has oil prices initially declining from current levels, then rising to current levels in real terms in 2030. We extrapolate this path from 2030 to 2050 given our longer projection period. In 2006 prices, this equates to an oil price of around $125/bbl in 2050.

- **Transport demand:** Passenger road growth of 0.7% pa out to 2050 is assumed compared to current growth of 1.2% pa. Commercial road growth of 2% pa out to

2050 is assumed compared to current growth of 3% pa. Bus growth of 4.6% pa out to 2050 is assumed compared to current growth of 2.3% pa. Aviation growth of 1.6% pa out to 2050 is assumed compared to current growth of 2.4% pa. Rail growth of 2.3% pa out to 2050 is assumed compared to current growth of 1.2% pa.

- **Hybrid vehicles:** in 2006, passenger and light commercial vehicles were deemed to require only 65 percent of the litres (or volume of gas) used by vehicles with only internal combustion engines for each 100km travelled. This ratio is assumed to improve to 50 percent of internal combustion engine fuel requirements by 2050. In keeping with the assumption of only mild hybridisation, the current fuel per 100km requirement is assumed to be 95 percent for trucks and buses, improving to 85 percent by 2050.

- **Plug-in hybrid vehicles (PHEVs):** PHEVs are assumed to be powered by electric battery for half their kilometres in a given year, with a fuel efficiency of 0.2kWh/km when operating on battery mode. PHEVs are assumed available in medium (1200–1500kg) and heavy (greater than 1500kg) passenger and commercial vehicle categories.

- **Electric vehicles (EVs):** operate with a fuel efficiency of 0.2kWh/km. EVs are assumed available in the light passenger and commercial vehicle categories (less than 1200kg).

- **Availability and cost of biofuels:** In regard to first-generation biofuels, estimates are obtained from O'Connell *et al*. (2007). With regard to second generation biofuels, lignocellulosic ethanol production is assumed to be available from 2020 at similar to current cost of ethanol from first generation technologies and feedstocks. It is assumed biodiesel can be produced from algae from 2020 at twice the cost of biodiesel from canola.

- **CO_2 capture and sequestration (CCS):** CCS is assumed to be commercially available from 2020 onwards. We have employed a cap of 115 Mt CO_2 per year that can be stored nationally as estimated by Bradshaw *et al*. (2004). For captured CO_2, a transport and storage cost of $10/t has been applied to any CO_2 stored.

- **Electricity generation technologies:** assumptions of technical performance and cost data for centralised and distributed electricity generation technologies are contained in Graham *et al*. (2007).

- **Full fuel cycle CO_2 emission factors:** estimates for fossil fuels are taken from AGO (2002a,b). Estimates for biofuels are obtained from O'Connell *et al*. (2007).

- **Policy settings:** it is assumed that the state renewable energy targets are replaced by the recently expanded Mandatory Renewable Energy Target (MRET). MRET seeks to increase the contribution of renewable energy sources in Australia's electricity mix to 45,000 GWh by 2020. The Queensland 13 percent gas target is assumed to remain in place until 2020. The NSW Greenhouse Gas Abatement Scheme (NGACs) is not extended beyond 2010 due to the introduction of emissions trading. Currently stated excise policy for transport fuels is assumed to remain in place. The NSW ethanol mandate is applied in the model as a constraint on the minimum use of E10 in fuel consumption.

5. Modelling results

The main results of interest are the extent of abatement achieved in the electricity and transport sectors from our scenarios and the degree to which there is convergence between the two sectors in regard to electric-powered transport. Figures 3 through 5 show the estimated annual greenhouse gas (GHG) emissions under the three emission reduction scenarios and the extent to which emissions are reduced in both sectors.

Figure 3 Estimated GHG emissions and target path EMS1990-60

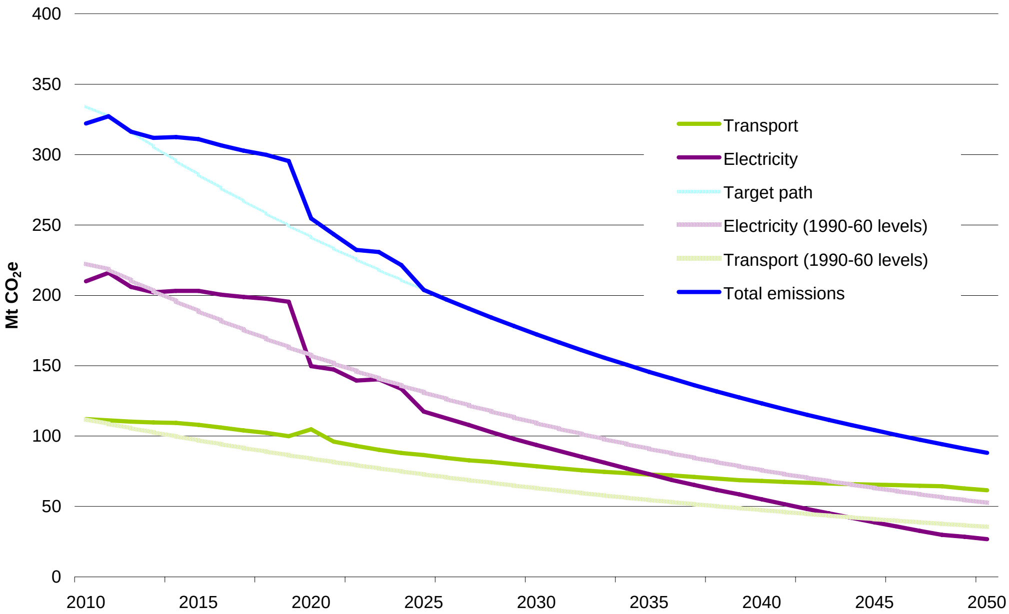


Figure 4 Estimated GHG emissions and target path EMS1990-80A

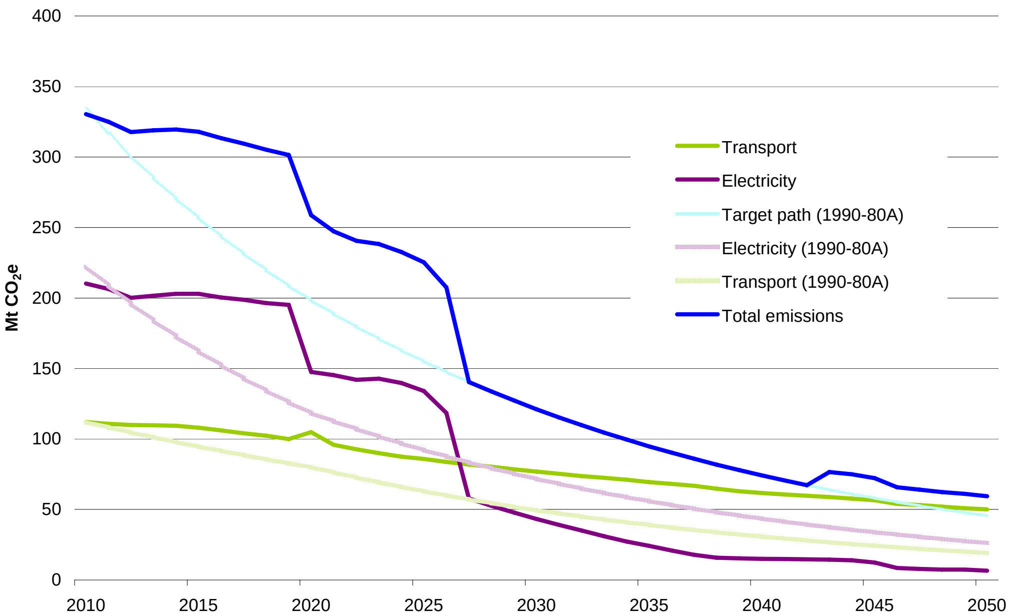
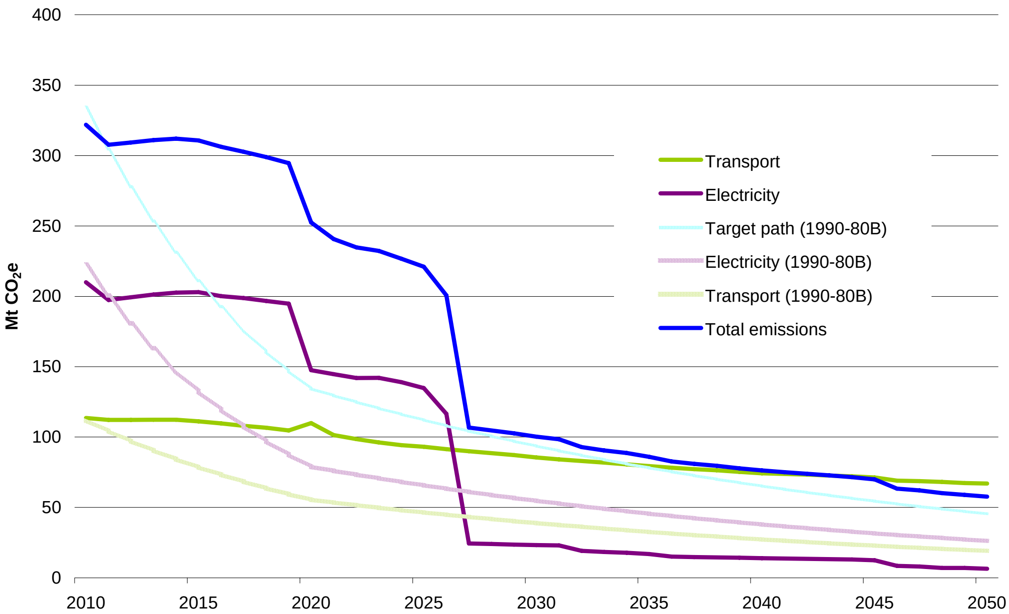


Figure 5 Estimated GHG emissions and target path EMS1990-80B



Figures 3 through 5 show that there are periods when the combined electricity and transport sectors fail to meet the emission reduction target. Under EMS1990-60, the sector is unable to reduce emissions in line with the target at a lower abatement cost compared to other sectors between 2013 and 2024. A more accentuated pattern occurs under EMS1990-80A with purchase of credits required between 2012 and 2026 and 2039 to 2050. In contrast, under EMS1990-80B, the electricity and transport sectors are unable to reduce emissions to meet the emission reduction target.

The volume of credits purchased from other sectors, reflecting the deviation of total energy sector emissions from its target path is shown in Figure 6. It clearly shows that reducing energy sector GHG emissions early on in an emissions trading scheme is a challenging task. The long lead-times in the availability of new low-emission technologies, the sunk cost of existing electricity generation assets and the slow turnover of the road vehicle stock, mean that lower cost abatement is located in other sectors.

Figure 6 Purchase of CO_2 permits from other sectors

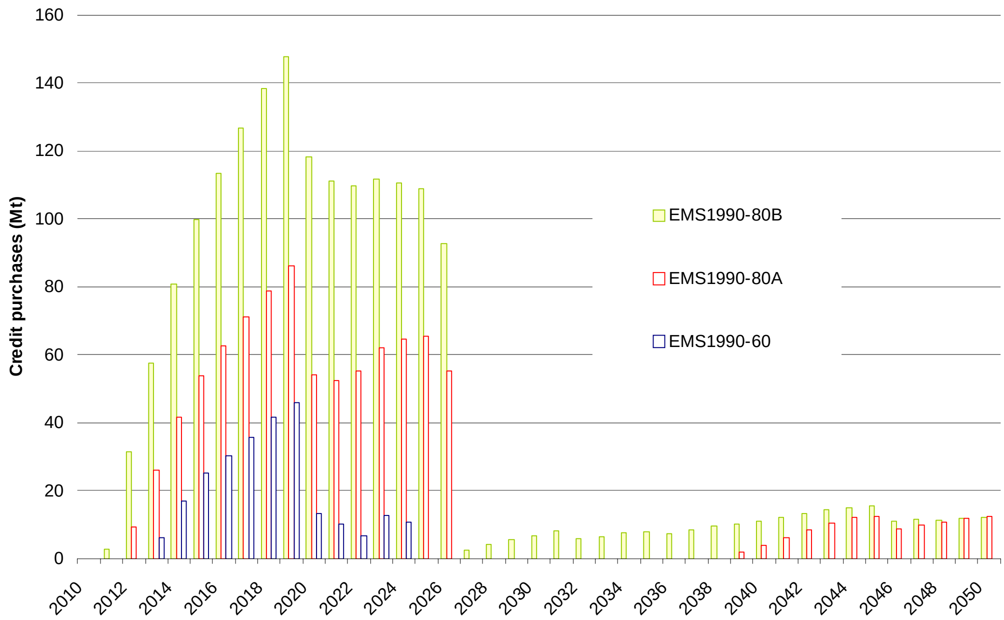
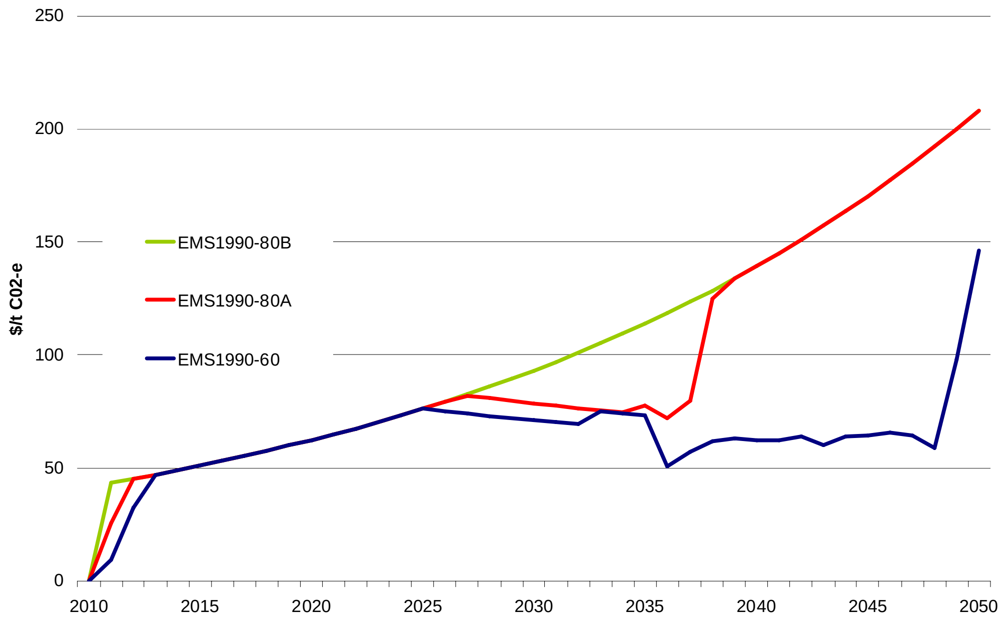


Figure 7 Estimated CO_2 permit prices



The estimated CO_2 permit prices displayed in Figure 7 reflect the marginal cost of abatement in a given year for the three scenarios. It shows that under EMS1990-80B, this is equal to the cost of abatement in other sectors (see Figure 2) in all time periods. Under EMS1990-80A, there are more time periods where the own cost of abatement within the energy sector is less than that outside it. Under EMS1990-60, the deviation below the abatement cost in other sectors is more significant.

It must be re-iterated that the marginal cost of CO_2 abatement is heavily influenced by the assumed abatement cost outside the energy sector (Figure 2) and the cost and availability assumptions of technology options within the energy sector. Similarly, structural design issues of the emissions trading scheme in regard to borrowing and banking of CO_2 permits would also impact on the estimated CO_2 permit prices.

Figures 3 through to 5 also show that, in general, the electricity generation sector has greater lower cost abatement options when compared to the transport sector. This is reflected in electricity sector emissions being below its 'equal share' of abatement towards the end of the projection period whereas the transport sector is above its 'equal share'. The figures also show that between 2020 and 2030 there is a rapid decline in electricity sector emissions reflecting significant deployment of low-emission electricity generation technologies. Figures 8 to 10 show the electricity generation mix for our three scenarios.

Figure 8 Electricity generation profile EMS1990-60

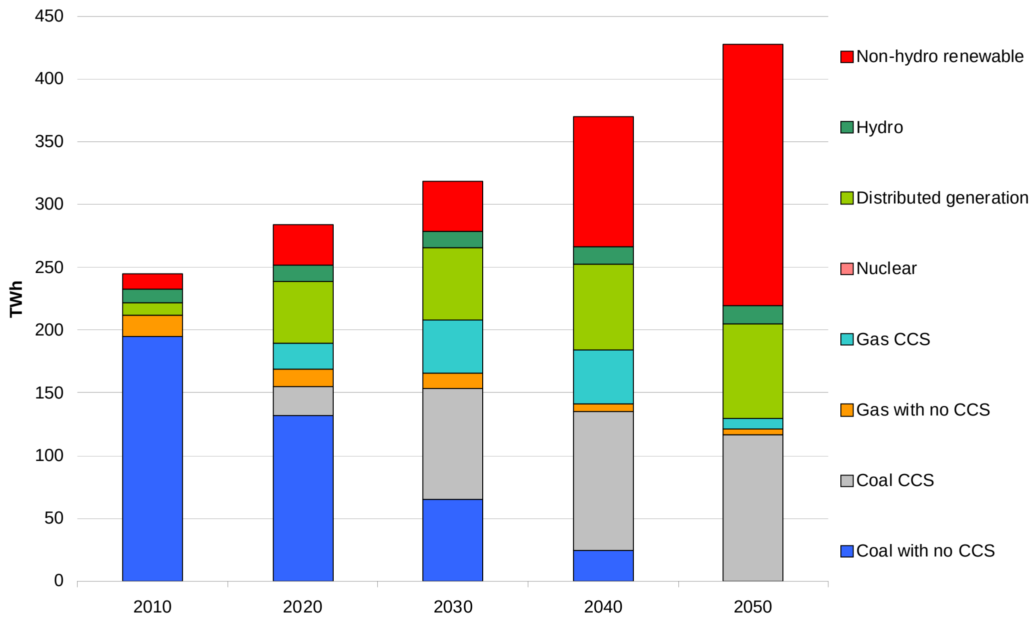


Figure 9 Electricity generation profile EMS1990-80A

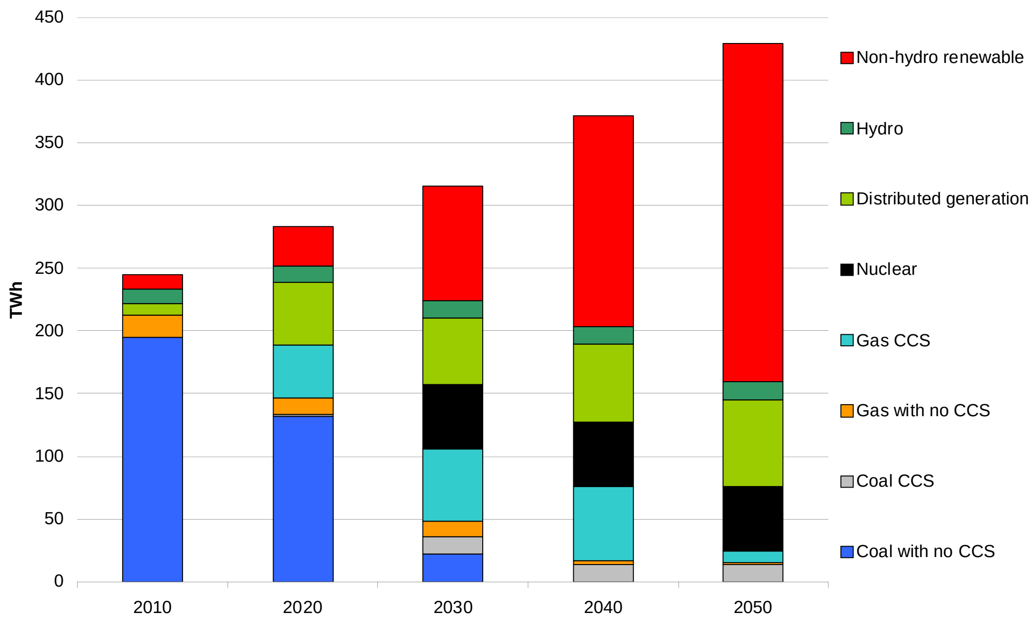
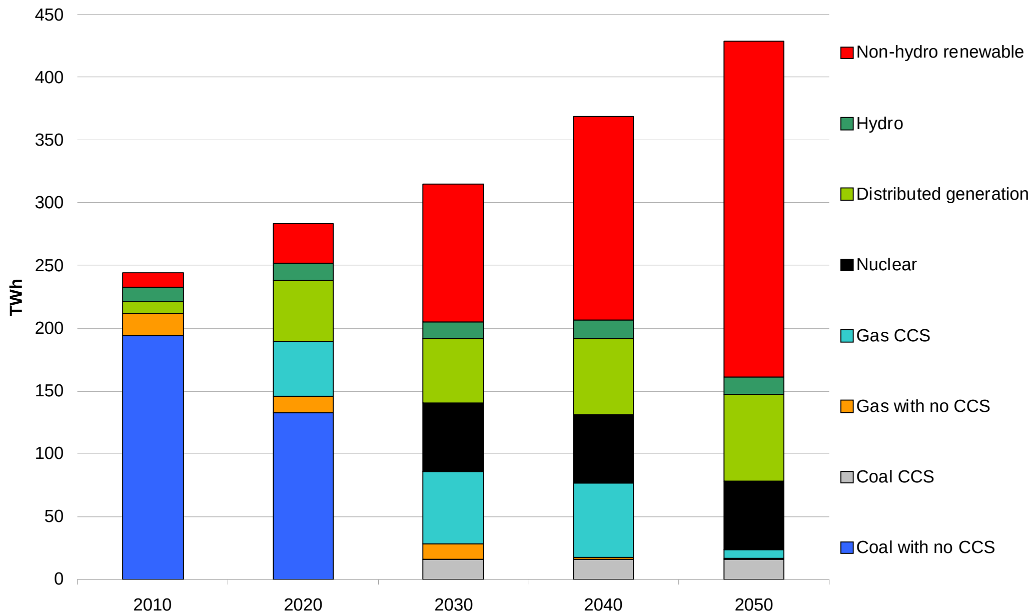


Figure 10 Electricity generation profile EMS1990-80B



The electricity generation profiles show that:

- In the near term (2010 to 2020), the proportion of high emission electricity generation (coal pf) is reduced in favour of gas-fired generation (centralised combined cycle plants and distributed (<30MW and close to load) gas turbines with combined heat and power), gas with full CCS, and wind farms;

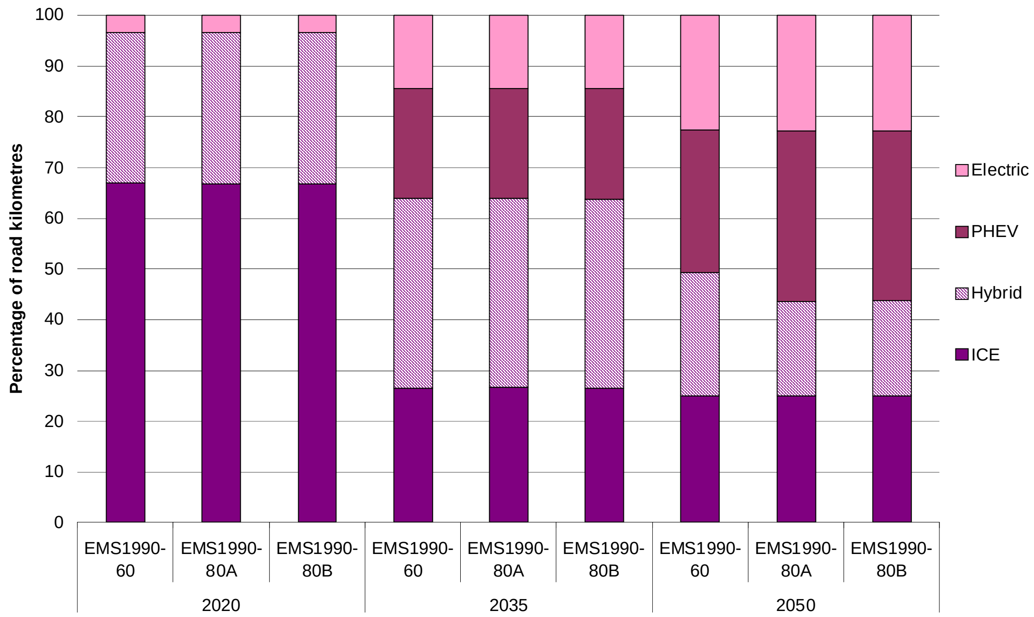
- In the medium term (2020 to 2030), there is significant deployment of coal and gas-fired generation with CCS in the EMS1990-60 scenario;

- In the medium term under the more stringent emission mitigation scenarios, there is greater deployment of zero emission technologies including non-hydro renewables (mainly hot fractured rocks and wind generation) and nuclear power; and

- Over the long term (2040 to 2050), non-hydro renewables dominate the electricity generation mix.

In regard to the degree of convergence between the two sectors, Figure 11 shows the extent of electric-powered transport.

Figure 11 Engine type in road transport under EMS scenarios



PHEV = Plug-in hybrid vehicle; ICE = Internal combustion engine

Figure 11 shows that over time, there is a progression away from internal combustion engines towards hybrid and electric vehicles. By 2050, under all scenarios, PHEVs have the greatest share of road transport propulsion, followed by highly efficient diesel engines, light electric vehicles and hybrid vehicles.

6. Conclusions

Under the modelling assumptions used, the key findings of this paper are:

- The presumption that the majority of energy sector CO_2 abatement will take place in the electricity sector is, in the main, supported by the modelling results in this paper;

- Although the transport sector does not meet its 'equal share' of energy sector abatement, its emissions do decline over the projection period principally through improvements in fuel economy, increasing preference for smaller vehicles and the deployment of electric powered vehicles (EVs and PHEVs). The increased use of electrically powered transport may proxy quasi-transport sector CO_2 abatement;

- The electricity sector almost fully decarbonises by 2050 under the EMS1990-80A and EMS1990-80B scenarios. This finding is consistent with other studies that have examined similar abatement targets in Australia (e.g., Hatfield-Dodds *et al.*, 2007) and the U.K. (e.g., DEFRA, 2007);

- Without further measures, the combined electricity and transport sectors are unable to meet aggressive cuts in CO_2 emissions in the medium term. The long lead-times in the availability of new low-emission technologies, the sunk cost of existing electricity generation assets and the slow turnover of the road vehicle stock, mean that lower cost abatement is located in other sectors;

- Over the long-term, the electricity generation sector has greater lower cost abatement options when compared to the transport sector; and

- More stringent targets reveal that the electricity and transport sectors have significant abatement options, but do require additional CO_2 permits.

The modelling results need to be considered with some caution. A key limitation 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.

Development of the integrated model used in this paper is on-going. Avenues for further research include:

- More detailed representation of the non-road transport sector to determine the extent of CO_2 abatement potential, especially from air travel;

- Incorporation of marginal CO_2 abatement functions for other sectors to explicitly account for CO_2 abatement potential from other domestic sectors;

- Exploration of sensitivities around key assumptions including oil prices, changing consumer preferences on transport mode choice and the timing of availability of low-emission technology options; and

- Revision of transport sector technology assumptions based on input from the Future Fuels Forum.

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