PLANNING FOR ELECTRIC VEHICLES IN AUSTRALIA – CAN WE MATCH ENVIRONMENTAL REQUIREMENTS, TECHNOLOGY AND TRAVEL DEMAND?

Michael A P Taylor, Peter Pudney, Rocco Zito, Nicholas Holyoak, Amie Albrecht and Raluca Raicu
Institute for Sustainable Systems and Technologies, University of South Australia, Adelaide, Australia

Abstract

According to the Garnaut report, Australians need to reduce their per capita CO_2 emissions to five per cent of 2000 levels by 2050. This will not be easy, particularly for transport. It will require both significant changes in travel behaviour, and significant reductions in vehicle emissions. Electric vehicles recharged from renewable energy sources will play an important role in reducing vehicle emissions. But there are several policy and infrastructure issues that need to be addressed to encourage the uptake of electric vehicles:

- per capita CO_2 emissions targets must be sufficiently stringent to stabilise atmospheric CO_2 at a sustainable level
- the cost of CO_2 must be high enough to cause the required emissions reductions
- published vehicle CO_2 emission data should be based on well-to-wheel emissions for all vehicles
- subsidies or tax benefits may be required to offset high initial costs associated with new clean vehicle technologies
- standards for public and private charging infrastructure are required
- standards for demand management of electrical loads will be required, to cope with both increasing demand and with supply variability (as the proportion of electricity generated from renewable sources is increased).

This paper addresses these questions, and provides a number of important recommendations for transport planning and management.
Keywords: Electric vehicles, travel demand, energy demand, vehicle emissions, climate change

1. INTRODUCTION

The Garnaut report on the impacts of climate change on the Australian economy was released in September 2008. A major recommendation in the report concerned the need to limit CO_2 in the atmosphere to no more than 450 ppm. Per capita emissions trajectories necessary to achieve this are shown in Figure 1, which is taken from Garnaut (2008). The implication of this graph is that Australian per capita CO_2 emissions have to be reduced to 60 per cent of 2000 levels by 2020, and to *five per cent* of 2000 levels by 2050. Indeed, the trajectories continue to decrease beyond 2050. Transport accounts for about 14 per cent of CO_2 emissions in Australia, and about half of this is due to cars and light commercial vehicles. Drastic reductions in vehicle emissions and changes in vehicle use will thus be required if per capita transport CO_2 emissions are to reduce at the same rate as the overall per capita CO_2 trajectory, which is not an unreasonable requirement if the overall target is to be met. Furthermore, the emissions of the car fleet respond slowly to reductions in new car emissions. Even if new car CO_2 emissions were to drop to 160 g/km by 2015 and then to 115 g/km by 2025, the mean light vehicle emissions in Australia will still be about 170 g/km in 2030 (ATC and EPHC 2008), which is well above the level corresponding to the Garnaut trajectory. Under current scenarios, vehicle emission reductions will almost certainly lag behind other sectors. Something else is therefore required.

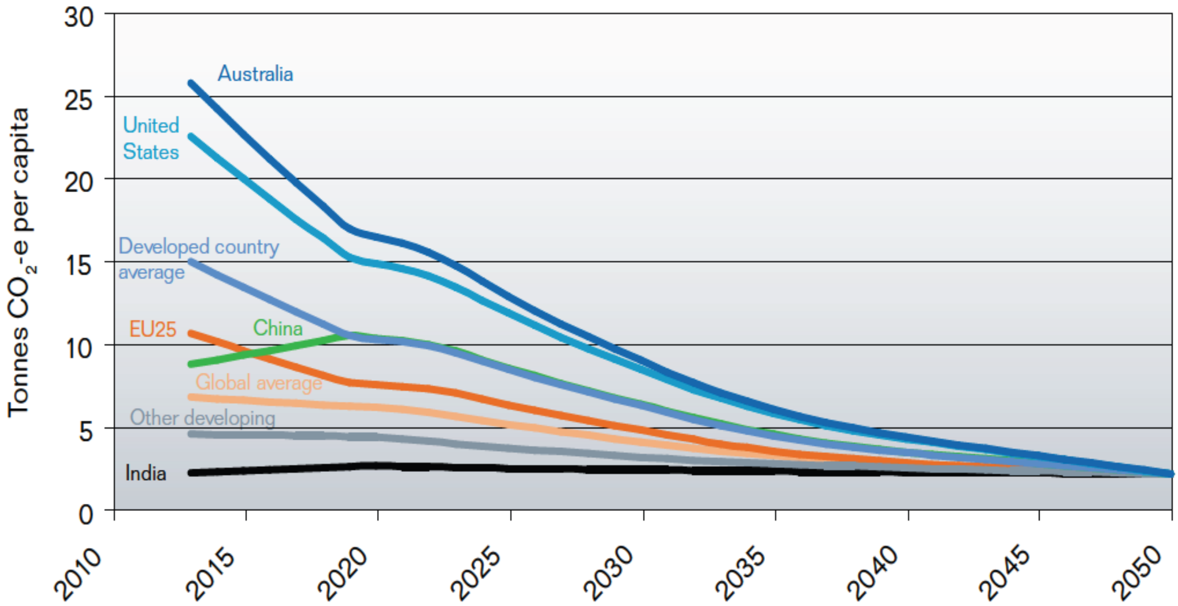

Figure 1: Trajectories of required per capita reductions in CO_2 emissions for stabilisation of the atmospheric CO_2 concentration at 450 ppm by 2050 [source: Garnaut (2008, Figure 9.5)]

2. REDUCING VEHICLE EMISSIONS

Technology improvements alone will not be enough to reduce emissions to the extent indicated by the Garnaut trajectory; behavioural change will also be critical. We need to choose more efficient vehicles, drive more efficiently, and change the way we use our vehicles. The CO_2 emissions of 1–2 tonne fossil-fuelled vehicles can be reduced by at most 30 per cent by incremental technological change (King 2007, Fuel Economy Guide 2008, PriceWaterhouseCoopers 2008). Table 1 indicates the potential emissions reductions for the internal combustion engine using improved technology. Note that not all of these technological improvements are complementary, in fact some are mutually exclusive.

Table 1: Potential reductions in CO_2 emissions for liquid fossil fuel vehicles using improved technologies

Technology	Reduction in CO_2 (%)
Homogeneous charge compression ignition (HCCI)	15-25
Smaller engine with turbo- or super-charging	6-15
Direct injection and lean burn	10-13
Vehicle mass reduction	10
Engine stop/start with regenerative braking	6
Cylinder deactivation	7-8
Variable valve actuation	5-7
Continuously variable transmission	6
Dual clutch transmission	4-5
Reduced mechanical friction components	3-5
Engine stop/start without regenerative braking	3-4

Incremental technology improvement is already available. For instance, King (2007) found that, for the UK, choosing the best-in-class vehicle in any market segment could reduce CO_2 emissions by an average of 25 per cent. A similar analysis for Australia, using data from Greenwheels (2008), indicates that the best-in-class CO_2 emissions are 20-50 per cent lower than the 222 g/km target for new vehicles in 2010, as recommended by the Federal Chamber of Automotive Industries.

In addition, vehicle size and mass have a significant effect on vehicle energy use and CO_2 emissions. Figure 2 shows the relationship between vehicle mass and CO_2 emissions for new cars currently available in Australia. The CO_2 emissions data is from the Green Vehicle Guide (2008), July 2008. Vehicle masses were obtained from manufacturer websites by Valenzisi and Dawson (2008). In the diagram, colour is used to indicate fuel type: green is petrol/electric hybrid, purple is diesel, red is petrol and orange is LPG. Trend lines are shown for petrol/electric hybrid, diesel and petrol vehicles (there is insufficient data to draw a trend line for LPG). The trend lines are:

Hybrid: $E(CO_2) = -26.6 + 0.105m$

Diesel: $E(CO_2) = -2.78 + 0.122m$

Petrol: $E(CO_2) = -2.61 + 0.152m$

where $E(CO_2)$ (g/km) is the CO_2 emissions rate per unit distance and m is the vehicle mass (kg). The diagram also illustrates the variations in emissions performance between different vehicles of similar mass and fuel type.

Figure 2: CO_2 emission rates and vehicle mass for new vehicles in Australia, 2008

We need to move quickly towards low-emission and zero-emission vehicles. For city driving–up to about 150 km per day–electric vehicles are ideal because they can be recharged using renewable energy with almost no emissions. Long-distance travel, and in particular freight transport, will still require the high energy density and fast refuelling capability of liquid fuels, and perhaps gaseous fuels[1]. Plug-in hybrid vehicles, which use electricity for short journeys and liquid fuels for long journeys, are a good compromise for vehicles that can be used for a mix of long and short journeys.

In Australia, about half of all new vehicles are sold to fleet operators. Encouraging fleet owners to purchase low-emission vehicles could have a significant impact on vehicle emissions[2]. Irrespective of the technologies, we need vehicle emissions targets that will encourage the large reductions in CO_2 emissions necessary for sustainability in the transport sector.

3. ELECTRIC VEHICLES

One technology that can contribute to attaining sustainable transport is that of electric vehicles, including electric-assisted bicycles, electric scooters and motorcycles, and electric passenger vehicles. The main advantage of electric vehicles is that they can be recharged using electricity generated from clean, renewable energy sources and at a lower environmental and monetary cost than a petrol or diesel car. Electric vehicles are not a new idea; many of the first mass-produced cars were electric. The main disadvantage of electric vehicles is that they have limited range and long recharge times compared to fossil-fuelled vehicles, and so cannot match the versatility of conventional cars. However, recent advances in lithium ion battery technologies, as well as concerns about emissions from conventional vehicles, indicate that electric vehicles are becoming viable again, particularly for the short commutes that make up almost all of the trips made by conventional cars. Plug-in hybrid technologies using energy from the electricity grid for short trips, supplemented by energy from petrol or diesel for longer trips are a reasonable compromise for vehicles that must be used for a combination of long and short trips. However, they are more complicated than comparable diesel or pure electric vehicles, and will have higher emissions than a diesel vehicle on long trips (because they are carrying a heavy battery that is not being used), and higher emissions than a pure electric vehicle on short trips (because they are carrying a heavy motor that is not being used).

Gaines et al (2007) calculated total life-cycle emissions for different energy pathways used to power a midsized car for urban and suburban driving. The emissions include those associated with vehicle production, use and disposal, and include one battery change for vehicles using batteries. The drive systems considered were petrol, diesel, petrol-electric hybrid, petrol-electric plug-in hybrid, and hydrogen fuel cell. The energy pathways considered were:

- *refined oil*, from various sources, used to provide petrol for conventional and hybrid cars, diesel for conventional cars, and to generate electricity to recharge plug-in hybrids

[1] The 2008 Academy of Technological Sciences and Engineering (ATSE) *Symposium on Alternative Transport Fuels for Australia* concluded that gaseous fuels and biofuels derived from non-food sources were going to play an increasing role in long distance transport.

[2] One issue here is the current high cost of electric vehicles. At present an electric vehicle is likely to cost about twice as much as an equivalent conventionally fuelled vehicle. In the longer term this price differential should reduce as production levels for electric vehicles increase. Before then, however, incentive schemes such as the purchase price subsidy scheme operating in Japan, with support from both the national government and prefectures, may need to be considered. This is an area for ongoing monitoring and further research

- *natural gas*, used to provide compressed natural gas and Fischer-Tropsch diesel for use in conventional cars, to generate electricity to recharge plug-in hybrids, and to generate hydrogen for fuel cell vehicles
- *coal*, used to produce Fischer-Tropsch diesel for conventional cars, and to generate electricity for plug-in hybrids
- *farmed trees*, used to generate ethanol (E85) for use in conventional cars and plug-in hybrids, and to generate electricity for recharging plug-in hybrids
- *wind and solar*, to generate electricity for plug-in hybrids and hydrogen for fuel cell vehicles.

The most efficient energy pathway for each fuel is shown in Table 2 (Gaines et al, 2007). Note that the last row in this table is the emissions from a standard petrol-engine car, for comparison. Gaines et al (2007) also gave emissions from other pathways. The life-cycle emissions from a plug-in hybrid recharged from a new standard coal-fired power station was 258 g/km, which is about the same as for a petrol car.

Table 2: Most efficient passenger car energy pathways for alternative fuel sources [source: Gaines et al (2007)]

Lifecycle greenhouse gas emissions rate (g/km)	Energy pathway
40	Wind and solar electricity generation, plug-in hybrid
40	Combined cycle electricity generation from farmed trees, plug-in hybrid
142	Natural gas combined cycle electricity generation, plug-in hybrid
180	Oil, petrol-electric hybrid car
218	Integrated gasified coal combined cycle electricity generation, plug-in hybrid
258	Coal-fired power station, plug-in hybrid
257	Oil, conventional petrol, spark ignition

Gaines et al (2007) concluded that plug-in hybrids can sharply reduce oil use and greenhouse gas emissions per kilometre if the electric energy used to recharge them comes from renewable sources. They did not consider pure electric vehicles in their analysis. The emissions from pure electric vehicles should be lower than plug-in hybrids.

Electric vehicles should play an important role in sustainable mobility. Most major automotive companies have announced that they are developing new electric vehicles, and some companies already have vehicles available for on-road use. There are however, a number of important questions to consider for the widespread use of electric vehicles:

1. Given the shorter operational range of electric vehicles, does electric vehicle technology offer a viable alternative in terms of travel demand and vehicle usage?
2. Do (or will) our electrical power generation and distribution systems have the capacity to provide the required energy for the widespread use of electric vehicles?
3. Given that the use of electricity as a transport energy source transfers the generation of greenhouse gases from the transport sector to the power generation sector, what are the actual likely outcomes for CO_2 emissions?

The remainder of this paper considers these questions.

4. VEHICLE USAGE IN AUSTRALIAN CITIES

The impact of electric vehicles will depend on the uptake of these vehicles. Account must also be taken of their reduced range compared to fossil-fuelled vehicles. This section summarises the factors influencing uptake and the transport implications of electric vehicles in selected urban regions. Further information is available in Albrecht et al (2009a).

A key consideration for an electric vehicle is its range. The range of an electric vehicle is defined as the maximum distance that can be travelled on a single charge of the batteries. The driving ranges quoted for electric vehicles typically fall between 60 and 160 km, depending on the weight of the vehicle, battery capacity, traffic conditions, terrain and the type of driving – as is the case with conventional vehicles. Automobile manufacturers are currently indicating ranges of 100-160 km for their proposed electric vehicles. If equipped with high capacity batteries, this range could be extended to beyond 160 km (EV World, 2009). Electric vehicle range tests are specified in Australian Design Rule 81/02 and UN ECE Regulation 101. However vehicle ranges indicated by these tests may not be representative of range achieved in real-world driving. This is particularly important for vehicles with low range and long recharge times.

4.1 Vehicle usage

Data on vehicle ownership, vehicle usage and fuel usage are available from a number of sources, including the ABS *Survey of Motor Vehicle Use* (ABS 2007, 2009) and *Australian Transport Facts* (Apelbaum 2008). In addition, data on personal travel is available from household travel surveys conducted in major urban areas. The databases established from the surveys provide detailed and non-identifiable household information including:

- household attributes: vehicles, household and family structure type, number of vehicles and bicycles
- personal attributes: age, gender, employment status, income, driving licences
- travel behaviour: trips per day by mode and purpose, expenditure, timing, origin and destination.

It is possible to determine travel behaviour, travel patterns, travel distances and the nature of household structures from these databases, and to estimate distributions of daily distance travelled by passenger vehicles. These distributions indicate the requirements for vehicle range under present travel demands.

The capital cities of Adelaide and Sydney were selected for analysis as they are representative of the large (3+ million) and medium (1-2 million) metropolitan areas in Australasia and because of the availability of high quality travel behaviour data for these two cities[3]. The analysis involves the 100 km electric vehicle range established previously with a focus on typical weekday travel by various modes. The term *daily journey* was used to define the total out-of-home travel that an individual will perform over an entire day (24 hours). Albrecht et al (2009a) provides an analysis of all travel in the two cities, but the focus in this paper is on motorised travel only.

[3] The household travel data for Sydney are collected by the NSW Travel Data Centre. The Adelaide data are collected by the SA Department for Transport, Energy and Infrastructure.

Motorised personal travel in Australian capital cities is achieved by private and public transport modes. Travel in a private vehicle can be accomplished as either a passenger or driver and the distances travelled by each will often have differing characteristics. Passengers can be 'dropped off' at destinations whilst the driver is always with a vehicle, although this vehicle may change throughout the day as a driver is not restricted to use the same vehicle at all times. All public transport modes are combined in this analysis as interchanges are common and individual modal analysis is not essential in this context. In the case where a traveller uses, for example, a car to travel to a bus stop and then a bus for the rest of the journey, travel distances for each mode are separated and represented accordingly. Figures 3 and 4 summarise the total journeys made for each travel distance for the motorised modes in Adelaide and Sydney respectively.

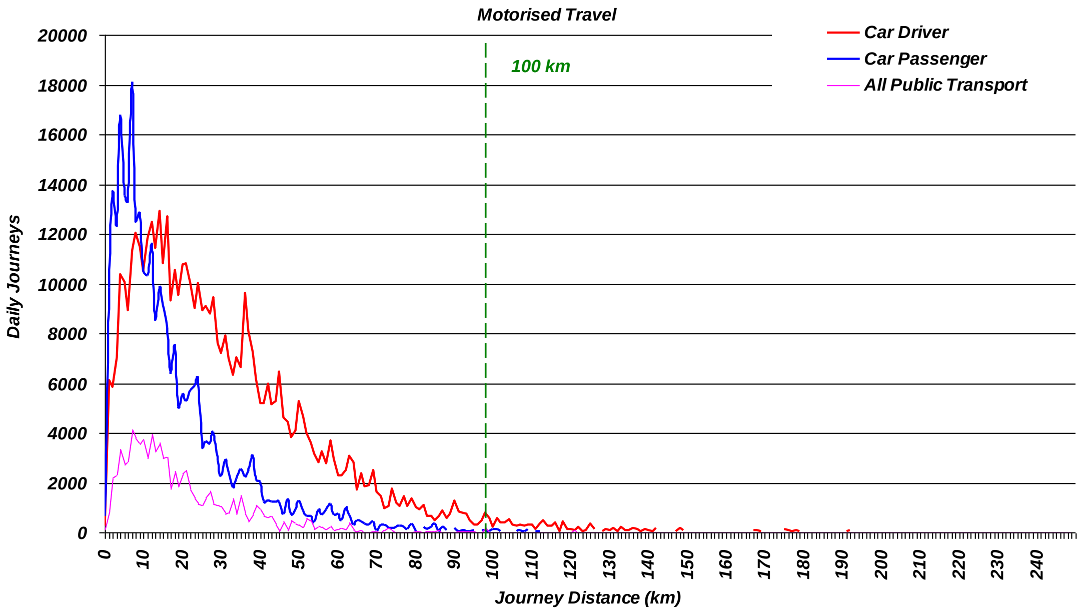

Figure 3: Adelaide daily journey distance distribution for motorised modes

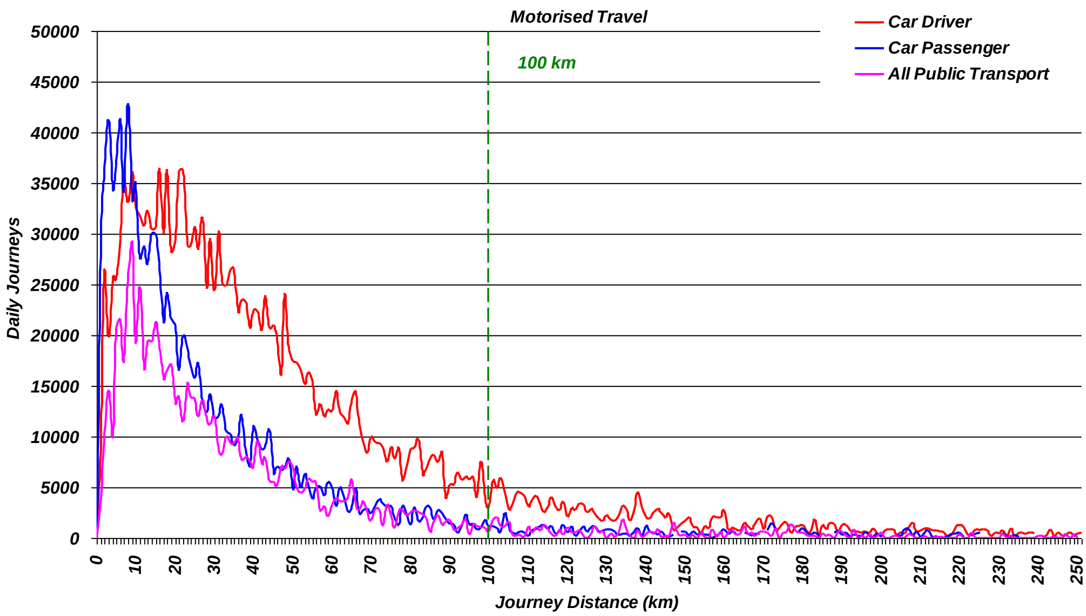

Figure 4: Sydney daily journey distance distribution for motorised modes

In both Adelaide and Sydney the amount of car driver travel is greater than car passenger travel and public transport travel. More car-driver trips also exceed 100 km, whilst the vast majority of car passenger and public transport journeys are within the range of an electric vehicle. This is analysed further in Albrecht et al (2009a). Comparison of Figures 3 and 4 indicates that Sydney has both a greater proportion of public transport journeys and a greater total amount of journeys by all modes. Sydney also has more journeys that extend beyond the 100 km range than Adelaide, especially when considering the car driver travel mode.

Table 3 shows the percentile travel distances for both Adelaide and Sydney. This table shows that in Adelaide between 95 per cent and 99 per cent of car driver travel is less than 100 km. In Sydney travel distances for this mode are longer; between 85 per cent and 90 per cent of car driver travel is under 100 km. The observations and data analysis presented here relate to average daily travel as reported in household travel surveys. It should be noted that the distribution of journeys achieved by all cars on a given day will not be the same as the distribution of journeys done by a particular car over many days. For example, some cars may rarely travel more than 100 km, whereas others may regularly travel more than 100 km.

Table 3: Percentile car driver travel distances in Adelaide and Sydney

Percentile	City	Distance (km)
50^{th} percentile	Adelaide	26
	Sydney	36
85^{th} percentile	Adelaide	55
	Sydney	91
90^{th} percentile	Adelaide	64
	Sydney	113
95^{th} percentile	Adelaide	79
	Sydney	157
99^{th} percentile	Adelaide	117
	Sydney	270

4.2 Vehicle uptake

Predicting uptake of electric vehicles is difficult. Instead we have analysed the impact of electric vehicles for scenarios where five, ten, 20 and 50 per cent of the journeys under 100 km (within the electric vehicle range) are transferred from conventional to electric vehicles in Sydney and Adelaide. The analysis considers the effect only on car driver journeys. Emissions results are summarised in the next section. Table 4 summarises the number of car driver journeys made and the total distance travelled by electric vehicles for each uptake scenario. The last row shows the total number of journeys and the total distance travelled for all journeys, including those over 100 km.

The results in Table 4 demonstrate that even a five per cent uptake in Adelaide results in 25,000 trips or 740,000 vehicle kilometres. The same uptake rate has a far greater impact in Sydney with a transfer of 90,000 trips or 3,260,000 km to electric vehicles from the car-driver traveller class. Uptakes greater than five per cent have a greater impact on the kilometres transferred to electric vehicles; a 50 per cent uptake in Sydney gives a transfer from conventional to electric vehicles of 32.56 million kilometres. This would have a significant impact on the use of liquefied fuels, associated energy demands and environmental impacts.

Table 4: Summary of uptake sensitivity analysis

Percentage of journeys < 100 km made by electric vehicles	Total daily vehicle journeys made by electric vehicles		Total daily vehicle kilometres made by electric vehicles (million)	
	Adelaide	Sydney	Adelaide	Sydney
5 %	25,012	90,507	0.74	3.26
10 %	50,023	181,014	1.48	6.51
20 %	100,046	362,029	2.96	13.02
50 %	250,016	905,092	7.42	32.56
All Journeys	*510,979*	*2,054,775*	*16.17*	*102.43*

Better insight into the nature of electric vehicle uptake may be gained from future research involving stated preference surveys of road network users to determine who will use electric vehicles and when and where they will be used.

5. POWER GENERATION AND DISTRIBUTION

There are three key issues related to charging electric vehicles: infrastructure requirements, capacity of the grid, and emissions. The first two questions are considered below. The third, which is perhaps the crux of the matter, is considered in Section 6.

5.1 Charging infrastructure

One advantage of using electricity as a fuel over new gaseous or liquid fuels is that it is widely available. Privately owned electric vehicles can be charged at home and typically overnight, with undercover parking at almost 85 per cent of Australian private dwellings (ABS, 1999). The inconvenience of long charge times is partly offset by the convenience of being able to charge at home each night, so that people can start each day with a full battery.

The flexibility of electric vehicles increases with the availability of public charging facilities, so that vehicles can be 'topped up' while they are parked, or given a fast charge during a long trip. Public charging infrastructure can be provided in parking stations, in car parks, at on-street parking spaces or at dedicated charging stations. A number of private companies (e.g. Better Place, 2008) are developing public charging networks, which will allow vehicles to be 'topped up' away from home.

5.2 Capacity

Electricity in Australia is mostly generated from coal (81 per cent), natural gas (12 per cent) and hydroelectricity (six per cent). In 2006/07, the generation capacity was about 52GW, and the total energy generated was about 227 TWh (ESAA, 2009). Supplying the electricity to customers typically requires:

- high-voltage transmission from generators to distribution networks, and
- low-voltage distribution from substations to customers.

Can Australia presently generate and distribute enough electricity to recharge electric vehicles? The following graph (Figure 5) provides an indication. It shows power demand in NSW for each day of 2007. Each coloured line shows the power demand on a particular day with the hue of each line indicating the day of the year: red is summer, blue is winter.

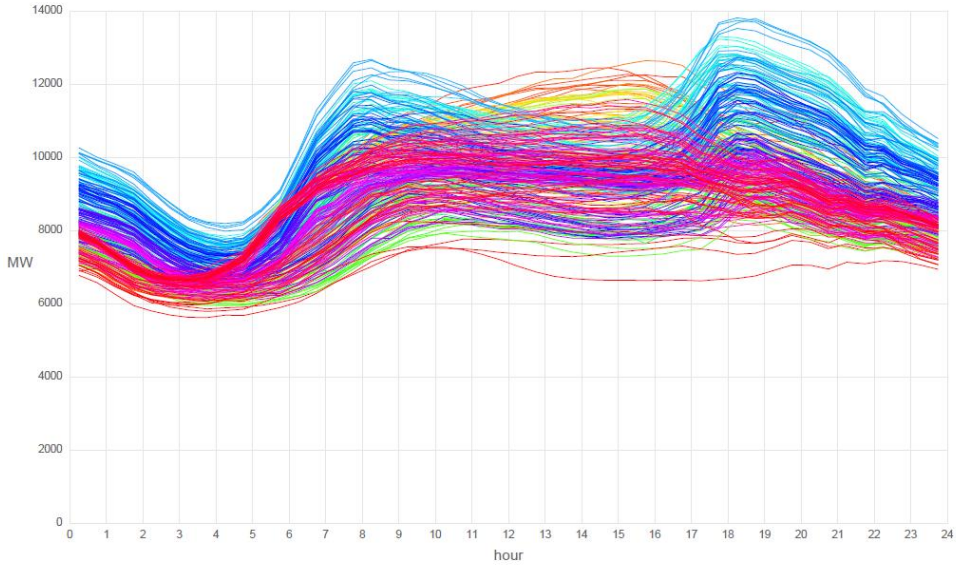

Figure 5: Temporal distribution of power demand in NSW for each day in 2007 (red is summer, blue is winter)

Albrecht et al (2009b) listed the estimated energy use for existing electric vehicle models and concluded that 160 Wh/km is a reasonable mean value. Assuming that the electrical supply system can reliably deliver power up to 90 per cent of the annual peak and that vehicles are recharged overnight between 18:00 and 06:00, we can then calculate how many kilometres of daily electric vehicle driving correspond to the minimum energy available overnight (see Table 5). As discussed in the previous section, daily distance travelled by car in urban areas can be calculated on the basis of the ABS Australian Survey of Motor Vehicle Usage (e.g. ABS 2007, 2009), which provides data on the number of vehicle kilometres driven annually in the capital cities and other urban areas on the main Australian electricity grid.

Table 5: Regional electricity supply and passenger vehicle km of travel

Region	Overnight GWh	Possible electric vehicle km/day (millions)	Current km/day (millions)
NSW and ACT	24.0	150	137
Victoria	17.1	107	124
Queensland	17.9	112	92
South Australia	7.6	48	25
Tasmania	2.7	17	10

Except in Victoria, the minimum overnight energy available for charging electric vehicles could meet the daily energy requirements of all vehicles used for capital city and urban area travel. As the number of electric vehicles increases, however, it will be necessary to implement charging strategies that manage the peak power demands.

There are, of course, variations in capacity within distribution networks, and the demand for electric vehicle charging capacity will also vary across suburbs. Business districts, in particular, are likely to require relatively greater capacity for public charging stations. Filling the troughs in power demand with electric vehicle charging will also impact on the cooling requirements of transmission and distribution networks, and on the ability to perform planned maintenance.

As mass-produced electric vehicles will become available within the next few years, electricity infrastructure planners need to prepare by modelling the likely uptake and distribution of electric vehicles, and determining detailed transmission and distribution requirements. To achieve significant reductions in transport CO_2 emissions, it is important that electric vehicles are recharged as much as possible using energy from renewable energy sources. Fortunately, the cost of 'GreenPower' is less than half the cost of petrol or diesel. New renewable energy sources equivalent to about 11 per cent of current electricity generation would be enough to power all city and urban travel (Albrecht et al, 2009c).

6. EMISSIONS IMPACTS

This section summarises the probable impacts on emissions for the uptake of electric vehicles discussed in Section 5. A full presentation of the emissions impacts is provided in Albrecht et al (2009d). The methodology adopted was based on the guidelines in the National Greenhouse Accounts (NGA) Factors (DCC 2008). The full NGA methodology could not be used, because the household travel surveys do not include details of the types of vehicles used for travel or the fuels used by those vehicles. In order to make a reasonable estimate of emissions, the average fuel consumption of a generic vehicle, irrespective of fuel type, for each mode of travel was required. A value of 11.5 L/100 km was calculated.

6.1 Emissions factors for vehicles

A generic emission factor was derived using the NGA method and the energy intensity and emissions factors for petrol, diesel and LPG as shown in Table 4 are taken from DCC (2008). The Scope 1 factors represent tank-to-wheel emissions. In order to obtain the full fuel cycle emissions, an allowance must be made for the Scope 3 emissions that are associated with the extraction, processing and transportation of the fuel to the users. Scope 3 emissions factors are available as kg CO_2e/GJ. The figures shown in Table 6 below are converted to the more appropriate units of kilograms of CO_2e per kilolitre of fuel consumed by multiplying by the appropriate energy intensity. It then follows that the mean Scope 1 + Scope 3 emissions rate for liquid fossil-fuelled private cars in Australia is about 280 g CO_2e/km.

Table 6: National Greenhouse Gas Inventory (NGGI) energy intensity and emissions factors (DCC, 2008)

Fuel	Energy Intensity (GJ/kL)	Emissions Factors		
		Scope 1 kg CO_{2e} / GJ	Scope 3 kg CO_{2e} /kL	Scope 1 + Scope 3 kg CO_{2e} /kL
Petrol	34.2	66.92	181	2470
Diesel	38.6	69.81	205	2899
LPG	26.2	60.20	139	1716
Weighted average				**2437**

Electric vehicles produce no tailpipe emissions, but require energy from the electricity grid in order to recharge their batteries. The emissions intensity of energy obtained from the grid is highly dependent on the fuel sources used to produce the electricity. Nationally, the main fuel sources for electricity generation are black coal, brown coal, natural gas, hydroelectricity, and renewable energy sources such as wind and solar. Each of these fuel sources has different emissions intensity, and the proportion of use varies from state to state. Hence electric vehicle emissions factors depend on the region in which the electric vehicle is recharged. Since this report deals with travel in SA and NSW, we present emissions factors for these states.

For electricity use, the emissions produced when fuel is burned are known as Scope 2 emissions rather than Scope 1 emissions. Scope 3 emissions include the emissions associated with fuel production and with electricity distribution. DCC (2008) includes Scope 2 and Scope 3 emission factors for electricity generation and distribution by state. For NSW and SA, the DCC Scope2 + Scope3 emissions factors are: (1) NSW 1.06 kg CO_2e/kWh and (2) SA 0.98 kg CO_2e/kWh. The next step is to derive the energy use per kilometre of travel for electric vehicles. Albrecht et al (2009b) listed the estimated energy use for various electric vehicles and concluded that 160 Wh/km is a reasonable mean. We assumed that recharge energy use will vary from 120 to 200 Wh/km, with a mean of 160 Wh/km. The resulting emission factors are shown in Table 7.

Albrecht et al (2009d) performed a similar analysis to determine a generic emissions factor for public transport of 124 g CO_2e/passenger-km.

Table 7: Estimated emissions factors for electric vehicles in NSW and SA under present conditions

	Wh/km	NSW CO_2e g/km	SA CO_2e g/km
Small electric vehicle	120	127	118
Medium electric vehicle	160	170	157
Large electric vehicle	200	212	196

Note: If electric vehicles are recharged from renewable energy sources, there are no significant CO_2e emissions.

Figure 6 shows a comparison of these emission rates, as well as 122 g CO_2e/km corresponding to the well-to-wheel emissions for a petrol vehicle with a fuel consumption of 5.0 L/100 km. It is interesting to note that the generic public transport emission factor is at the same level as the small electric vehicle. While initially this could indicate that the use of small electric vehicles instead of public transport travel could lead to lower emission totals, this is not desirable because a decrease in public transport patronage will lead to other secondary effects such as an increase in congestion, which would cause higher fuel consumption or energy consumption per kilometre of travel.

6.2 Emissions for the uptake analysis

Figure 7 shows the change in CO_2 emissions as the proportion of car driver distance travelled in electric vehicles increases. Electric vehicles have the potential to reduce the total CO_2e emissions in each state by around five per cent, and to reduce transport contribution to total CO_2e emissions by around 30 per cent for each state. Whilst these are significant reductions, there are at least two issues that need to be explored further if reductions of this magnitude are to be achieved:

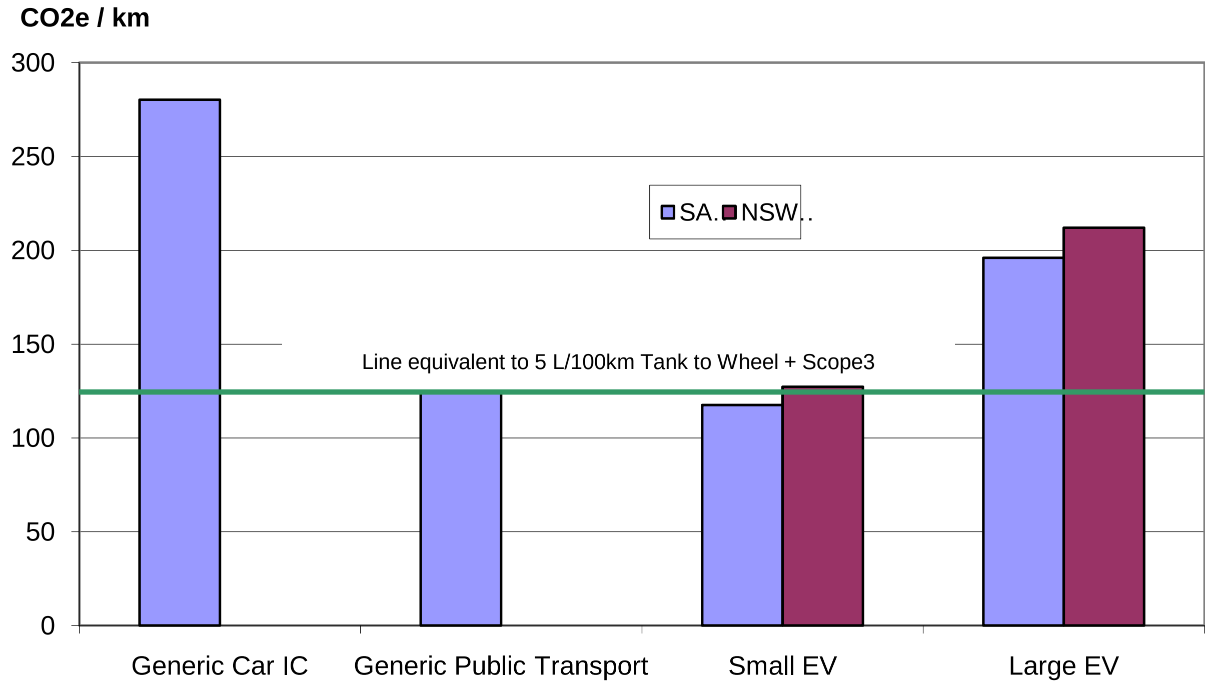

Figure 6: Comparison of emission factors by mode, including a generic value for public transport

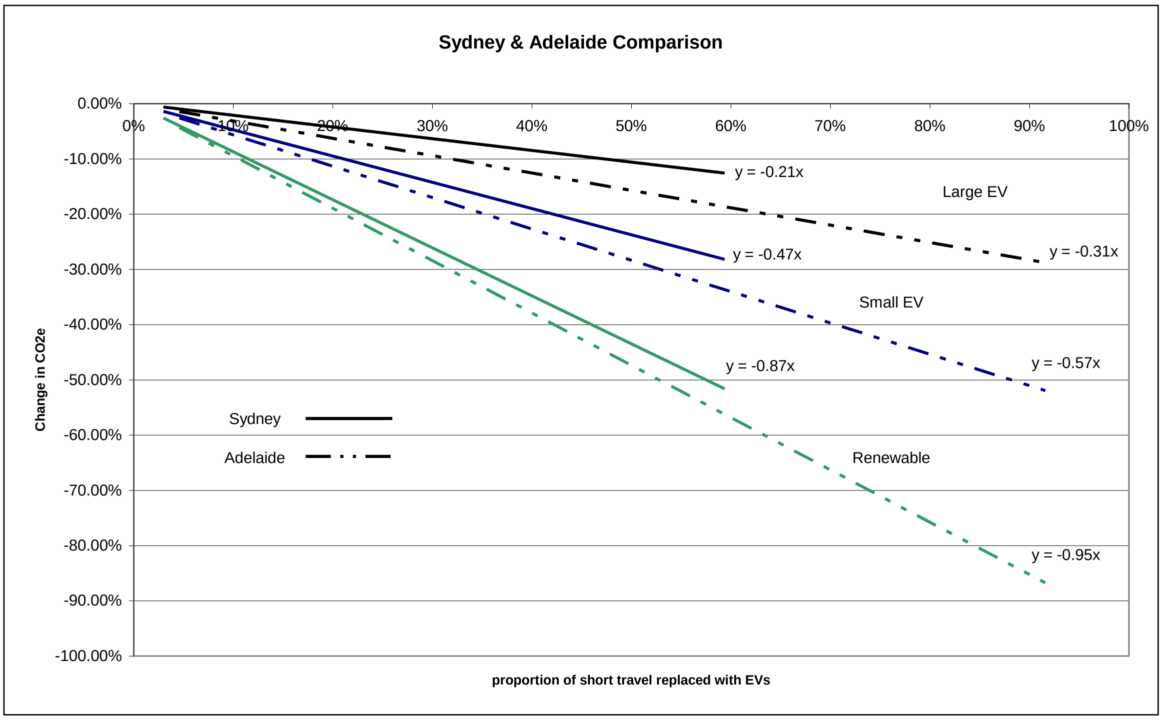

Figure 7: Percentage change in CO_2 emissions for the uptake of electric vehicles in Sydney and Adelaide

1. travel behaviour will play a significant role in determining the potential uptake of electric vehicles and the journeys that will be displaced. The emissions modelling method used in our research employed a sensitivity analysis approach to quantify the emissions reductions

that can be achieved for various scenarios. More work is required to conduct qualitative research on travel behaviour change in order to determine not only the potential uptake of electric vehicles over time, but also determine the types of journeys for which these vehicles would be used, and

2. there is a necessity to charge electric vehicles from renewable energy sources if there are to be significant reductions in emissions. We need policies that encourage the uptake of electric vehicles, and then ensure that these vehicles are recharged from renewable energy sources.

7. CONCLUSIONS

If we want to continue using cars the way we currently do, and transport is to remain at 14 per cent of per capita CO_2 entitlements, we need reductions in the vehicle fleet CO_2 emissions to 60 per cent of 2000 levels by 2020, and five per cent by 2050. To achieve this, new vehicle CO_2 emissions must halve every decade (Albrecht et al 2009b). Fossil-fuel technologies are not going to achieve this. We need to move to much cleaner technologies, we need to change the ways we use motor vehicles, and we need to start now.

An introduction of current technology electric vehicles could impact significantly on daily journeys made within the 100 km charge range. The case examples of Adelaide and Sydney show that the large majority of motorised journeys[4] are accomplished within this range, an observation expected to provide a similar result for all Australian capital cities. In Sydney it appears possible to achieve a reduction of 90,500 fuelled vehicle trips and a 3.26 million km reduction in kilometres travelled by liquid fuelled (predominantly petrol) vehicles with only five per cent use of electric vehicles on daily journeys. In Adelaide it is possible to achieve a reduction of 25,000 fuelled vehicle trips and a reduction of 740,000 fossil-fuelled kilometres with five per cent electric vehicle use.

It must also be emphasised that for a maximum benefit from electric vehicles, electricity should be acquired from renewable sources. Replacing emissions from liquid fuels with those from coal-fired power stations will have only a small reduction in CO_2 emissions. The impact of electric vehicle uptake on public transport and non-motorised modes should also be considered as a result of introducing electric vehicles. Transport planning authorities will seek to replace car trips, but do not want transfers from other modes (public transport, walking, cycling) to electric vehicles, as this may contribute significantly to traffic congestion. While an electric vehicle recharged using renewable energy may have lower CO_2 emissions per person-km than a bus or train, it will contribute much more to road network congestion.

Mass-produced electric vehicles are likely to be available in Australia within the next few years. As the initial numbers of vehicles will be small, they will have little impact on the electricity supply and distribution networks. But we need to start preparing for widespread use of electric vehicles. In particular, the following considerations are essential:

- development of charging standards
- deployment of public charging infrastructure
- upgrading the electrical distribution system
- smart chargers, to avoid overloading household or neighbourhood electricity supply

[4] Albrecht et al (2009a) also showed that all non-motorised journeys are also accomplished within the 100 km range, but we will not argue that electric vehicles should be considered as a substitute for these journeys as well.

- renewable energy generation.

Electric vehicles will play a vital role in reducing vehicle emissions, but must be recharged using energy from new renewable energy sources if we are to realise the full potential emissions reductions.

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