Economic viability of electric vehicles in metropolitan New South Wales

David Adams, Katie Feeney and Matthew Yi

AECOM, for the NSW Department of Environment, Climate Change and Water

Email:

David.Adams@aecom.com

Katie.Feeney@aecom.com

Matthew.Yi@aecom.com

Abstract

Electric vehicle technology has the potential to contribute to an increasingly sustainable Australian transport sector. Electric vehicles may, depending on how electricity is generated, cut greenhouse gas emissions while reducing Australia's exposure to rising oil prices.

This study estimated take-up of electric vehicle variants through the use of a choice model that allowed the assessment of various price sensitivities. Thereafter, this study assessed the economic viability of electric vehicles in the context of metropolitan New South Wales and identified the market and economic conditions under which plug-in electric vehicles can provide a net benefit to society.

The choice model predicted a transition to hybrid electric vehicles (HEVs) in the short term (5 to 10 years), plug-in electric vehicles (PHEVs) over the medium term (5 to 20 years) and pure electric vehicles (EVs) over the longer term (over 20 years). The study concluded that the PHEV market in NSW was both economically and financially viable over the long term.

This study identified that vehicle supply constraints and the availability of charging infrastructure were important barriers in the take-up of electric vehicles. Policy should focus on these factors if the take-up of plug-in electric vehicles is to be encouraged.

1. Introduction

Lithium-ion (pure) electric vehicles (EVs) are on the verge of commercial viability and mass-production, with plug-in hybrid electric vehicles (PHEVs) following close behind (Amirault et al. 2009, Simpson 2008). Our research identified that in the next three to five years, the industry as a whole plans to launch more than 30 new EV and PHEV models with global production targets set to reach almost one million units annually within this timeframe (AECOM with Dr. Andrew Simpson 2009, Deutsche Bank 2009, Victorian Automobile Chamber of Commerce 2010). Both EVs and PHEVs are currently in commercial production and are expected to be available to Australian motorists by 2012.[1]

The production of EVs and PHEVs is expected to be launched in all segments of the light-vehicle market. However, manufacturers of EVs are showing an early preference for small

[1] A recent article says Mitsubishi is planning to have the "i-Miev" commercially available in Australia sometime in 2011. The Renault-Nissan alliance expects to introduce "the Leaf" in Australia by 2011 - 2012 (see "Mitsubishi awaits go-ahead to lead electric charge", The Australian Financial Review, 10 June 2010). Toyota has also recently teamed with Tesla motors to develop a range of electric vehicles and parts (see "Toyota teams up with electric vehicle manufacturer Tesla to build Evs", Sydney Morning Herald, 21 May 2010).

vehicles in order to minimise the cost premium since battery cost increases proportionally with vehicle size and weight, whereas mature internal combustion engine vehicle (ICE) costs vary less with vehicle size and weight (Amirault et al. 2009, Leduc et al. 2009). The price premium of EVs and PHEVs is driven largely by battery costs which are typically around US$10,000 (AECOM with Dr. Andrew Simpson 2009).

EVs and PHEVs will provide the same functionality and features as traditional vehicles, except for some obvious differences with regards to range per charge and recharging versus refuelling.

The evolution of lithium-ion battery technology will see continuing advances in performance, range and useful life as a result of significant ongoing investment in battery research and development. It is expected there will be significant cost reductions in vehicle prices through industry learning curves as this is still a relatively new market, and economies of scale achieved through mass-production (Anderson 2009, BCG 2010, Deutsche Bank 2010).

Electric vehicle technology is likely to play an important role in the future of motor vehicles in Australia. Electric vehicles may, depending on how electricity is generated, cut greenhouse gas emissions and ambient air pollution, while reducing Australia's exposure to crude oil prices and oil import dependency.

The increased awareness of the potential benefits of electric vehicles by public entities has motivated research regarding the desirability of the electric vehicle market and any potential scope for government to provide industry assistance and consumer incentives. Therefore, this study, undertaken for the Department of Environment, Climate Change and Water, aimed to identify the market and economic conditions under which electric vehicles are economically desirable and identify if there is a role for government for supporting the electric vehicle market.

To forecast demand for different engine configurations, AECOM implemented a vehicle choice model. Forecasts of new vehicle purchases were used in the economic and financial appraisals to assess viability. The economic model considered the costs and benefits to infrastructure providers, consumers (in terms of vehicle purchase and operating costs) and externalities such as greenhouse gas emissions and air pollution. The financial model considered the costs and benefits only to infrastructure providers and consumers.

2. Methodology

This study assessed the economic and financial viability of electric vehicle variants, including PHEVs, for various market segments in metropolitan New South Wales.[2] This study identified market and economic conditions under which such vehicles provided a net benefit to society (i.e. scenarios where the net present value was positive). Analysis of specific business models (such as battery leasing arrangements) and financing arrangements were outside the scope of this study

2.1 Scenarios and market segments

Electric vehicle demand depends on various underlying drivers for which there are a range of possible values. The models implemented in this study facilitated sensitivity testing around key factors. For instance, it is expected that the adequate availability of electric vehicle charging infrastructure will play an important role in a vehicle-buyer's decision making process. In Australia, there is significant uncertainty surrounding charging infrastructure

[2] The study area was defined as "metropolitan NSW" which included the Sydney Statistical Division, Illawarra Statistical Division and the Newcastle Statistical Subdivision.

availability. Therefore, developing a model that included scenarios that explicitly accounted for different levels for it was deemed desirable since associated costs will have an important effect on the viability of the electric vehicle market. The scenarios considered in the cost benefit analysis were:

- **Base Case:** Assumed availability of internal combustion engine vehicles and hybrid electric vehicles (HEVs) but no availability of PHEVs or EVs. All other scenarios were compared against the Base Case.
- **Scenario 1:** Assumed availability of (level 1) household charging only. Level 1 charging can be undertaken through a standard power outlet (all charging electronics required to support level 1 charging can be carried on board of the vehicle).
- **Scenario 2:** Assumed availability of household charging level 1 and level 2 and availability of level 1 and 2 public charging facilities (car parks, hotels, shopping centres, street parking) within the NSW metropolitan region. Level 2 charging requires a “charging interface” to be wired into a building’s electricity supply to provide necessary protections from the higher voltages/powers. Level 2 charging can be undertaken at home provided that the adequate equipment has been installed by an electrician.
- **Scenario 3:** Assumed availability of household charging level 1 and 2, availability of level 2 public charging stations and availability of electric vehicle service stations that offer quick battery recharge or battery replacement. Level 3 charging will not occur at home, as it exceeds capacity of typical residential circuits, but at purpose-built commercial or industrial facilities.

As the costs and benefits of electric vehicle use will vary for different users, this study segmented the market of passenger vehicles in three: by vehicle size (small, medium, large), by distance travelled (low, medium and high vehicle kilometres travelled (VKT)); and type (light commercial vehicles (LCV) and taxis). Vehicle size was considered because it impacts on potential externality emissions and because prices and availability of vehicles vary significantly between vehicle sizes. Distance travelled was considered because VKTs influence the financial viability of buying different types of vehicles.

2.2 Vehicle choice model

A common approach found in the electric vehicle literature is to make assumptions on the demand for different vehicle engine configurations. As such, a key innovative element of this study was the direct estimation of take-up for different electric vehicle technologies based on a vehicle choice model.

Directly estimating take-up provided two main advantages. Firstly, as this is a new market, it was less meaningful to make *a priori* assumptions on the future of electric vehicles in Australia based on emerging experience elsewhere. Secondly, by directly estimating take-up it was possible to assess the demand sensitivity to various price factors (electricity price, fuel price, vehicle price).

After an extensive literature review, it was determined that the most important factors affecting the vehicle purchase decision included vehicle price, fuel cost, vehicle range, tailpipe emissions, availability of recharging infrastructure, and the option of using different fuel types. AECOM selected a multinomial logit model to estimate the take-up of different engine configurations that included all of these important variables.

A multinomial logit structure was chosen as it is transparent, easily understood by stakeholders and does not require assumptions on the degree of heterogeneity in vehicle choice.

2.2.1 Estimating the vehicle choice model

In emerging markets such as that for electric vehicles, determining vehicle market shares would usually benefit from the collection of primary data through stated preference surveys. Yet, since collecting stated preference data is expensive and time intensive, a common approach is to use parameter values from available stated preference studies. The use of parameters from the literature implied the development of a synthetic model. [3]

AECOM's synthetic multinomial logit model used the following variables (for which base and future year values were assigned) for each engine technology:

- Vehicle price
- Running costs
- Vehicle range
- Tailpipe emissions
- Availability of recharging infrastructure
- A multi-fuel vehicle constant
- Constants for each vehicle type

The parameter value for each of these variables was based on judgments on:

- Relative parameter values guided by willingness to pay values extracted from previous studies
- The scale of the parameters guided by known elasticities
- Initial market shares by existing vehicle classes.

Given the wide variation across willingness to pay values for improvements to key vehicle attributes identified in the literature (see Appendix A), AECOM, instead of accepting any specific value, determined appropriate willingness to pay values that were consistent with the lower bound values given by the literature and adapted[4] them to a NSW context. For instance:

- Willingness to pay for fuel efficiency assumed that Australians drive on average 15, 000 km per annum. A 1 cent per km saving equated to a saving of $150 per annum. A $1,050 upfront payment was equivalent to 10 years of fuel savings, discounted at 7 percent per annum.
- Willingness to pay for vehicle range seemed to be quite high in the US (typical of the long distance driving patterns prevalent in the US). A slightly lower willingness to pay was assumed for Australian conditions – set closer to the Norway figure.

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[3] A vehicle multinomial logit model is called synthetic when elasticities are imposed on, rather than derived from, the choice model and where constants are calibrated to better reflect current market shares of existing vehicle classes.

[4] The adoption of choice model parameters without any adjustments is likely to result in an over/underestimation of the shift in demand away from ICE powered vehicles as alternatives become cheaper and efficient.

The final set of willingness to pay values adopted by AECOM is shown in Table 1.

Table 1: AECOM willingness to pay values for five vehicle attributes (in AUD 2009)

Measure	Improvement in fuel efficiency by 1c per km	Improvement in range from 100 km to 200 km	Decrease in emissions to 90% of ICE emissions	Increase in recharging facilities from 10% to 20% of petrol stations	Multi-fuel capacity
Value	\$1,050	\$3,000	\$500	\$2,000	\$5,000

After determining the willingness to pay values for each key vehicle attribute, the parameter values for each of the variables in question were derived. As a start, the *absolute* value for the fuel cost parameter was determined given the availability of a fuel elasticity estimate drawn from the meta-analysis undertaken by Goodwin, Dargay & Green (2003).[5] Additional assumptions required to solve the fuel cost parameter are shown in Table 2.

Table 2: Fuel cost parameter assumptions

Description	Values
ICE fuel price elasticity (Goodwin, Dargay & Green 2003) [6]	-0.25
ICE fuel cost rate	10 c/km
Initial ICE market share	85%

In multinomial logit models, direct price elasticities can be estimated using the values of the beta parameter, price and the market share as shown in Equation 1.

Equation 1: Multinomial logit direct price elasticity

$$\eta = \beta X(1 - \rho)$$

where η is the elasticity, β is the response parameter to changes in the variable X (e.g. price), and ρ is the market share.

Adapting this to fuel cost gave:

Equation 2: Multinomial logit direct fuel price elasticity

$$\eta_{fuel} = \beta_{fuel} X_{fuel} (1 - \rho_{ICE})$$

Rearranging Equation 2, and using the assumptions shown in Table 2, gave:

Equation 3: Estimating the beta fuel parameter

$$|\beta_{fuel}| = \left|\frac{-0.25}{10(1 - 0.85)}\right| = |-0.167| = 0.167$$

[5] Support for these values is provided by a recent study for Australia regarding fuel price elasticities, which identified elasticity values of similar magnitude to the one used here (see Breunig & Gisz 2009).
[6] Note that the fuel elasticity used here is the median fuel price elasticity value found in Goodwin, Dargay & Green (2003).

2.2.2 Calculating final model parameters

With the absolute value of the fuel cost parameter established, the absolute value of the vehicle price parameter was calculated by rearranging the willingness to pay equation shown as Equation 4.

Equation 4: Calculating the vehicle price parameter

$$WTP_{fuel} = \frac{\beta_{fuel}}{\beta_{vehicle\ price}}$$

With the vehicle price parameter established, the willingness to pay assumptions shown in Table 1 were used to establish the *absolute values* for all other parameters.

The values shown in Table 3 were given a sign based on the expected effect of positive changes in the variable on utility. For instance, an increase in charging infrastructure should cause an increase in an individual's utility; hence, a positive sign was assigned. On the other hand, an increase in vehicle price should cause a decrease in an individual's utility, hence a negative sign was considered appropriate.

Final parameter values for all model attributes are shown in the table below.

Table 3: Parameter values based on Table 1 willingness to pay values

Parameter	Units	Value
Vehicle price	$	-0.000159
Fuel cost	¢/km	-0.166667
Range	Km	0.004762
Tailpipe emissions	Proportion of ICE	-0.793651
Infrastructure	Proportion of ICE	3.174603
Multi-fuel bonus	Dummy	0.793651
EV constant	Dummy	0

Parameter values shown in Table 3 were then used to calculate utility (and hence probability through the multinomial logistic function) in the vehicle choice model. These utility calculations given for the years 2010 to 2040 were then used to determine the total new vehicle sales for each engine configuration (i.e. ICE, HEV, PHEV and EVs). Prior to this however, the vehicle choice model required information on all relevant variables. The following section discusses this in more detail.

2.3 Model variable assumptions

2.3.1 Vehicle prices

New vehicle prices were estimated from a survey of 34 global electric vehicle products for the 2009 to 2012 model years and 28 US HEVs for the 2009 to 2010 model years (AECOM with Dr. Andrew Simpson 2009). An equivalent ICE vehicle was used for the price of ICE vehicles to ensure a consistent comparison.

For future vehicle prices, it was assumed that PHEVs would be similarly priced to EVs, where such an assumption was based on the view that the cost reduction from having a smaller battery (relative to an EV) is offset by the cost of the internal combustion engine. Since a large proportion of taxis in NSW are Ford Falcons, prices for taxis were assumed to be the same as large passenger vehicles.

The survey of prices revealed that for HEVs available in Australia, there was a premium of around $10,000 over US prices. This is likely to reflect a local market penalty due to the relatively small market size in Australia, distance from large vehicle manufacturing countries, volatile exchange rate, and lack of local manufacturing of non-ICE vehicles. A similar small market penalty for PHEVs and EVs was also assumed.

Based on industry consultation, HEVs were assumed to reach price parity with ICEs in 2020. PHEV and EV purchase prices were assumed to reach price parity with ICEs in 2030. Due to the uncertainty around future prices, sensitivity testing on prices was undertaken.

2.3.2 Fuel cost per kilometre

Fossil fuel prices were estimated using Energy Information Agency forecasts for crude oil prices. Their reference scenario forecasts US$74 per barrel in 2010, decreasing slightly and then increasing to US$80 per barrel by 2040. Electricity prices were estimated based on modelling undertaken by the Australian Treasury (2008). The central price scenario sees electricity prices increasing to over 20 cents per kWh by 2040. The following assumptions on fuel efficiencies were made:

- Efficiency of an ICE vehicle will improve due to platform engineering as well as other efficiencies such as combustion technology improvements
- HEVs will experience continued efficiency gains over ICE however these improvements will decline over time as the potential for improvement is eroded by improved combustion technologies
- EVs will experience improvements in efficiency due to platform engineering and power-train improvements
- PHEVs will use the electric drivetrain for 50 percent of VKT in 2012 increasing to 80 percent in 2035.

2.3.3 Supply constraints

A major issue to the take-up of electric vehicles in the short term (next 5 to 10 years) will be supply constraints. Global supply constraints are expected until at least 2012 and these will be exacerbated in Australia which is not seen as a key market for vehicle manufacturers. As such, a supply constraint was included in the model to ensure it reflected current market conditions. AECOM identified current planned global production of electric vehicles. It was assumed that 1 percent of global production would be available in Australia and that supply would be constrained until 2020.

2.3.4 Cost of Infrastructure

The cost of infrastructure included the cost to physically install the different levels of infrastructure as well as any costs involved with upgrading the electricity network to support the charging infrastructure.

It was assumed there would be no requirements to upgrade the electricity transmission and distribution networks beyond business as usual network enhancements.[7] This assumed the availability of smart metering (so that households charge during the off peak period) and that significant investments were known in advance so they could be built into investment plans with little additional costs. However, an increase in network access cost was assumed to

[7] Forecast retail prices used in the modeling accounted for the costs of business as usual network enhancements.

apply to all electricity consumed through Level 2 household charging to represent the costs of a potentially necessary upgraded household connection to the local distribution network.

The cost of charging infrastructure varied by scenario. There were no infrastructure costs associated with Scenario 1 (household charging). The infrastructure costs for Scenario 2 and 3 were as follows:

Scenario 2: Household charging (Level 1 and 2) plus public charging stations:

- $1,000 per household for interface unit installation (equipment cost included as standard item)
- $6,000 per public charging unit.

Scenario 3: Household charging (Level 1 and 2) plus EV service station:

- $1,000 per household for interface unit installation (equipment cost included as standard item)
- $6,000 per public charging unit
- $500,000 per charging station.

AECOM did not include the cost of additional generation capacity due to the use of electric vehicles. Under the higher electric vehicle take-up of Scenario 3, annual electricity consumption for EVs and PHEVs in 2039-40 (8.2TWh) represents an increase of around 10 percent of 2007 to 2008 total NSW electricity demand (78.3TWh[8]). However, general growth in electricity demand between 2008 and 2040 will reduce the significance of EV electricity demand as a proportion of total demand.

A summary of key assumptions is given in the **Appendix.**

3. Results

Table 4 sets out the present value of the benefits associated with introducing electric vehicles into the NSW market compared to the Base Case. The model showed that under all scenarios the electric vehicle market is both economically and financially viable over the long run. The net present economic value was positive *after* 2030 under all scenarios.

This was largely driven by the high vehicle purchase costs of alternative engine configuration vehicles decreasing over time and the operating cost savings increasing over time. In addition, there were large savings in greenhouse gas and air pollution emissions. Greenhouse gas emission savings totalled $33 million under Scenario 1, $91 million under Scenario 2 and $165 million under Scenario 3. Air pollution savings totalled $261 million under Scenario 1, $70 million under Scenario 2 and $1,256 million under Scenario 3.

The net benefits increased with the level of charging infrastructure provided because this increased the take-up of electric vehicles. Higher levels of charging infrastructure also brought forward the break-even year.

[8] ABARE (2009)

Table 4: Present value of benefits incremental to the base case

Benefits	Scenario 1			Scenario 2			Scenario 3		
	NPV (to 2020)	NPV (to 2030)	NPV (to 2040)	NPV (to 2020)	NPV (to 2030)	NPV (to 2040)	NPV (to 2020)	NPV (to 2030)	NPV (to 2040)
Vehicle purchase costs ($m) ***a***	-$272	-$1,230	-$1,230	-$415	-$2,010	-$2,313	-$625	-$2,766	-$3,192
Vehicle operation savings ($m) ***b***	$71	$461	$1,447	$133	$1,020	$4,008	$242	$1,694	$6,756
Net charging infrastructure costs ($m)** ***c***				-$1	-$15	-$37	-$3	-$26	-$65
Financial benefits ($m) ***d = a+b+c***	-$201	-$769	$217	-$283	-$1,005	$1,658	-$386	-$1,098	$3,499
GHG emissions savings ($m) ***e***	$3	$11	$33	$4	$21	$91	$7	$36	$165
Air pollution savings ($m) ***f***	$11	$82	$261	$21	$182	$70	$40	$319	$1,256
Net present economic value ($m) ***g = d+e+f***	-$187	-$676	$511	-$258	-$802	$2,459	-$339	-$743	$4,920
Breakeven year	2035			2032			2031		

***	NPV stands for net present value.**
Based on central forecasts of oil price, electricity price and CPRS policy. A 7percent discount rate has been used for all present value calculations.
****	Net charging infrastructure is capital cost of charging infrastructure minus premium customers pay to cover cost of infrastructure.**

Sensitivity analysis highlighted the following:

- Results were very sensitive to the year in which electric vehicles reach price parity with ICE vehicles. Changing the initial price did affect the results but this was not as sensitive as the year in which prices reach parity
- Results were sensitive to increasing oil prices but less so to electricity and the Carbon Pollution Reduction Scheme (CPRS) prices.[9] This was mainly due to the improved

[9] Anticipated CPRS prices were based on Treasury modelling; as at May 2010, the CPRS has not yet been enacted.

efficiency of electric vehicles over ICE vehicles. However, the combination of high oil prices with low electricity prices had large positive impact on the results.

Table 5 sets out the expected lifetime cost per kilometre for the different engine configurations in 2010 and 2040. The total cost of ownership includes the vehicle price, annual fuel[10] and maintenance costs (based on average annual distance travelled) and insurance. Future costs were discounted at 7 percent real (as per NSW Treasury guidance).

Table 5: Lifetime cost per kilometre for each engine configuration in 2010 and 2040[11]

Engine type	Small Passenger		Medium Passenger		Large Passenger		Light Commercial		Taxi	
	2010	2040	2010	2040	2010	2040	2010	2040	2010	2040
ICE	$0.263	$0.264	$0.286	$0.287	$0.353	$0.355	$0.277	$0.279	$0.271	$0.275
HEV	$0.299	$0.245	$0.318	$0.272	$0.380	$0.341	$0.299	$0.267	$0.l321	$0.267
PHEV	$0.297	$0.217	$0.313	$0.227	$0.469	$0.274	$0.365	$0.214	$0.466	$0.234
EV	$0.260	$0.191	$0.270	$0.199	$0.416	$0.243	$0.318	$0.185	$0.438	$0.220

In summary, the cost per kilometre for smaller pure electric vehicles was already cost competitive with ICE vehicles due to the fuel cost savings outweighing the high up-front vehicle price. As PHEVs and HEVs only achieved a proportion of the fuel cost savings, it took longer to offset the higher vehicle price. Conversely, large passenger vehicles and LCVs took longer to reach cost per kilometre parity with ICEs due to the high upfront price premium for large EVs, PHEVs and HEVs. However, once they reached parity, there were larger savings compared to an ICE due to the larger distances travelled. Taxis took longer to reach a cost per kilometre comparable to ICE vehicles and, even with vehicle price parity, the fuel savings were not as high as for other vehicles. This was due to the high use of LPG in taxis and the much shorter vehicle life.

4. Issues and further work

Several issues arose during the study that were not able to be incorporated into the model, but are important in understanding the electric vehicle market and how it may evolve over time. These included:

Battery issues:

- The evolution towards standardisation of technology
- The current high costs which are expected to reduce over time with increasing production resulting in economies of scale and industry learning curves[12]
- A lack of industry practices to ensure safe battery disposal; uncertainty about battery life
- The residual value and potential for a secondary market.

[10] Fuel prices are forecast out to 2040 and have been assumed to be constant thereafter.
[11] The cost per kilometre is non-scenario specific as vehicle and operating costs do not change significantly between the scenarios.
[12] Our modeling accounted for decreasing electric vehicle prices over time in line with expectations regarding learning curves and economies of scale in the electric vehicle market.

Global supply constraints: A major issue to the take-up of electric vehicles in the short term (next five years) will be supply constraints. These are likely to be exacerbated in the Australian market which is relatively small and not a key market for vehicle manufacturers.

Market structure: The current market structure of vehicle travel is characterised by vertical separation. The business models chosen by providers of electric vehicle infrastructure can have a strong influence on customer decision-making. While this should not change the fundamental cost and benefits of electric vehicle travel, it could change the perception of relative costs and benefits by customers and hence affect their choice of vehicle. It also has the potential to create competition issues.

Lifecycle considerations: The lifecycle of batteries and associated electric-drive components will clearly be a determining factor for the overall sustainability of the plug-in vehicle industry. Early efforts to characterise the lifecycle of electric-drive vehicles are revealing some positive indications. However, given Australia's current reliance on fossil fuels, the ongoing use of these fuels for the manufacturing processes and electric power generation will be a critical factor. Further, lifecycle assessment will be required based on Australia‘s unique local context.

Electricity issues: The most significant electricity issue arises in respect of how electric vehicle charging infrastructure is priced and how consumers respond. Clearly there is interplay between the cost of charging and convenience, which will affect the take-up of electric vehicles.

The role of government policies: Governments from around the world have developed policies to encourage the take-up of electric vehicles. Some policies are designed to support industry (charging infrastructure, development of technology) whilst other policies are to encourage increased demand through subsidising the purchase and operating costs for consumers. It is important to consider the applicability of these and other government policies in Australia.

Wider economic impacts: This study is a partial equilibrium model and as such there are a range of other effects that may occur as a result of changes in the vehicle market that have not been considered in this study.

4.1 Enhancing the choice model

Further work is suggested on refining the vehicle choice parameters.

It is preferred that revealed preference data is used to corroborate the relative shares predicted by a choice model based solely on stated preference data. However, there is minimal revealed preference data available on electric vehicle take up as this is a new market. What revealed preference data is available reflects the behaviour of early adopters rather than mainstream purchasers. Research suggests that early adopters have different purchasing habits to mainstream purchasers and in particular are less price sensitive. Furthermore, the relatively low take-up of non-ICE vehicles is likely to reflect the limited supply of these vehicles into the Australian marketplace rather than consumer preferences.

The stated preference data that is available on electric vehicle demand is dated and mainly from the US which does not fully reflect Australian driving conditions. For instance, TRESIS (2001) is the only known Australian study that has estimated electric vehicle demand. However, the TRESIS model is relatively old (uses 1991 revealed preference data) and reflects preferences based on previous generation electric vehicles which typically had lower vehicle performance. The data was also collected at a time when fuel prices were not as high and there was less concern with environmental issues. Recent vehicle sales data suggest people‘s preferences on vehicles have changed substantially over the past decade with a clear shift toward smaller, more fuel efficient vehicles. This suggests that the parameters used in TRESIS may not reflect how consumers would respond under current market conditions.

There is a lack of literature on how people's choices are affected by the distance they drive. As a result this could not be taken into account of within the vehicle choice model and separate assumptions were made to capture this impact.

A more up-to-date stated preference survey would allow for a more robust assessment of demand for electric vehicles under Australian driving conditions.

5. Conclusion

This study showed that the plug-in electric vehicle market in NSW was both economically and financially viable but only over the longer term. Purchase costs take time to repay benefits in the form of operating costs and externality savings (i.e. greenhouse gas emissions, air pollution).

The vehicle choice model predicted a transition to HEVs in the short term (5-10 years), PHEVs over the medium term (5-20 years) and EVs over the longer term (20 years plus). In the short term there was increased take-up of alternative engine configurations in the small vehicle category. Significantly, despite the high vehicle price, small EVs were around the same lifetime cost per kilometre as ICE vehicles in 2010 due to large fuel cost savings over the life of the vehicle. As vehicle prices fell, the vehicle range increased and more charging infrastructure became available, owners of larger vehicles and vehicles that travelled large distances purchased a higher proportion of EVs. This was attributable to operating costs being more important for these vehicle owners.

Higher levels of charging infrastructure (as represented in the different scenarios) significantly increased the take-up of plug-in electric vehicles and hence increased the viability of the market. Other key factors that affected both take-up and viability included the vehicle price and rate at which it converged with ICE vehicles (this is largely driven by battery costs), fuel prices (particularly higher oil prices), vehicle range and the existence of local supply constraints.

It is likely that vehicle price and vehicle range converge over time as technology improves and production increases, therefore the removal of supply constraints and the provision of charging infrastructure are key areas that warrant further attention by government and private institutions if the take-up of electric vehicles is to be encouraged.

6. Glossary

- ICE: Internal Combustion Engine
- HEV: Hybrid Electric Vehicle
- PHEV: Plug-in Hybrid Electric Vehicle
- EV: Pure Electric Vehicle

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Appendix A: Summary of key assumptions

Table 6: Willingness to pay values of selected studies

Study/Country	Improvement in fuel efficiency by 1c per km	Improvement in range from 100 km to 200 km	Decrease in emissions to 90% of ICE emissions	Increase in recharging facilities from 10% to 20% of petrol stations	Multi-fuel capacity
Bunch et al. (1993) ***Australia***	$1,800	$16,400	$1,200	$3,600	$10,400
TRESIS (2001) ***Australia***	$500	$1,900			
Brownstone et al. (2000) ***USA***	$2,500	$14,700	$400	$400	
Dagsvik et al. (2002) ***Norway***	$1,000	$3,600			
Ewing and Sarigollu (1998) ***Canada***		$1,600	$400		
Golob et al. (1996) ***USA***	$3,300	$11,200		$1,800	
Average	**$1,820**	**$8,233**	**$667**	**$1,933**	**$10,400**

Note: Ratios were drawn from referenced studies, updated to 2009 prices and are expressed in Australian dollars. Nearest hundred rounding applies.

Appendix B: Summary of key assumptions

This study considers a new market for vehicles powered by electricity that could develop over the next 30 years. There is much uncertainty around the future path of many of the key variables. This study has used the best available information to forecast variables and built a model that allows extensive sensitivity testing around key variables. The table below shows key assumptions made in this study.

Table 1: Summary of key study assumptions

Variable	Current Assumption / Suggested Sensitivity
General model assumptions	
Discount rate (economic evaluation)	7% Sensitivity at 4% and 10%
Discount rate (financial evaluation)	7% Sensitivity testing at 4%, and 10%
New vehicle sales assumptions	
Demand for new passenger vehicles	Assume grows at 1% per annum Sensitivity on different growth rates
Projections of new passenger vehicle sales by vehicle type	Currently assume shift from large to medium vehicles continues. In 2008: Small – 30% of new sales Medium – 45% Large – 25% Assume that this changes by 2020 to: Small – 30% Medium – 55% Large – 15% Sensitivity different % shift and different year
Proportion of VKT ranges in each vehicle size category	It is assumed that VKT proportions by vehicle type will be unchanged in the future
Proportion of new LCV sales	Assume grows at 5% per annum, declining to 3% per annum by 2030 Sensitivity on different growth rates
Taxis	Assume no increase in licences/vehicles
Vehicle price assumptions	
Fixed vehicle price	Prices based on global survey $10,000 premium in Australia compared to US prices No growth in ICE prices HEVs reach price parity with ICEs in 2020 PHEVs and EVs reach price parity with ICEs in 2030 Sensitivity on different prices and growth rates
Fuel efficiency	
Fuel type	Current fossil fuel mix remains same Passenger vehicles: 88% petrol, 5% diesel and 7% LPG LCV: 57% petrol, 34% diesel and 9% LPG Taxi: 100% LPG
Growth in fuel efficiencies	ICE: 37% between 2006 to 2050 HEVs: relative to ICE See **Table 4-14** EVs: 20% increase to 2050 PHEV: EV 50% of kilometres in 2006 increasing to 80% in 2030
Fuel cost	
Oil price	• High – corresponds to EIA (Energy Information Agency) high price scenario; • Reference – corresponds to the EIA reference scenario; and • Low – equal to a 20% discount from the reference scenario.
Base prices	Diesel 100% petrol price LPG 40% of base petrol prices
Excise	The current fuel excise is $0.381 and is applied to petrol and diesel. LPG tax is scheduled to begin on 1 June 2011 (assumed to be same as petrol excise)
CPRS	Price based on forecast by Treasury modelling Assume no pass through to fuel prices for first 3 years

GST	10%
Electricity prices	
Carbon emissions policy	Prices from Treasury modelling: Reference case – no additional emission reduction measures (also excludes expanded national renewable energy target) CPRS-5 – 5% reduction from 2000 emission levels by 2020 and 60% reduction by 2050 (includes NRET) CPRS-15 – 15% reduction from 2000 emission levels by 2020 and 60% reduction by 2050 (includes NRET)
Residential network charge	Equal to network charge as determined by Treasury Modelling50
Additional residential network charge	20% premium on residential network charge
Commercial charging station network charge	Equal to residential network charge plus a premium see **Section 4.10**
Public charging point network charge	Equal to residential network charge plus a premium see **Section 4.10**
Other vehicle costs	
Fuel cost per km	Derived from fuel efficiencies and prices for fossil fuels and electricity
Registration	Fixed registration from RTA. Assumed no growth
Insurance	Greenslip – no growth Comprehensive insurance – no growth
Maintenance	ICE – 13.45c/km HEV – assumed same as ICE (13.45c/km) PHEV – assumed 125% more than ICE (16.81c/km) EV – assumed 50% less than ICE (6.73c/km)
Other assumptions	
Range	ICE and HEV – 500km for small passenger; 550km for all other categories EV – range from 120km to 300km depending on vehicle category. See **Table 4-23** PHEV – range maximum of EV or ICE All grow over time in line with increased fuel efficiencies EVs also grow from 5% per annum increase in battery storage
Emissions	Derived from fuel efficiency, fuel emissions factor and vehicle segment
Infrastructure	Availability relative to ICE vehicles: ICE and HEV – 100% availability for all scenarios PHEV and EV – availability depends on scenario. See **Table 4-24**
Multi-fuel bonus	HEVs and PHEVs receive bonus Sensitivity undertaken with and without multi fuel bonus
Non-captive market	Proportion of market that may purchase EV or PHEV dependent on VKT and scenario See **Table 4-25**
Supply constraints	There are expected to be global supply constraints until at least 2012 and as such, a supply constraint has been built into the model to ensure it reflects current market conditions **HEV supply constraint** - 1,000,000 HEVs currently in global production, will grow by 35% per annum. Australia will receive 1% of global demand. Supply will be constrained until 2020 **PHEV supply constraint** - By 2012 there will be around 150,000 PHEVs in global production and 1% of these will reach Australia. Production will grow at 20% per annum and be constrained until 2020 **EV supply constraint** - By 2012 there will be around 500,000 EVs in global production and 1% of these will reach Australia. Production will grow at 20% per annum and be constrained until 2020
Cost of infrastructure	Base – no costs Scenario 1 – no costs Scenario 2 $1000 per household for interface unit $6000 per public charging unit Scenario 3 $1000 per household for interface unit $6000 per public charging unit $500,000 per charging station Different costs

For further information on assumptions and data sources please refer to the report available at http://www.environment.nsw.gov.au/cleancars/.