Framework to Evaluate Policy for Promotion of Electric Vehicles

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Abstract

The transport sector from conventional Internal Combustion Engine (ICE) vehicles is one of the largest contributors to greenhouse gas and carbon emissions. Due to growing environmental concerns, there is an increasing governmental interest in evaluating policies that can increase the uptake of Electric Vehicles (EV).

This study develops a framework to evaluate the impact of policies for EV uptake. Using the city of Sydney, Australia, as a case, the framework utilizes a system dynamic model that explicitly incorporates the life cycle of vehicles, consumer preferences, impact of infrastructure on choice, positive cascading effect on choice due to increased penetration of EVs as well as feedback effects of advertising. It was found that the EV uptake predicted by the model was the most sensitive to the capital and operational cost of the vehicle, based on which five policies were identified that would affect these variables. Finally, a cost benefit analysis was conducted to evaluate the policies. It was found that the government subsidy of 70% on electricity rates for charging electric vehicles was the most cost effective. Though this framework was used in Sydney, this methodology provides planners a tool through which they can evaluate policies related to uptake of new vehicle technologies

Introduction

Emission of greenhouse gases becomes an increasingly significant issue affecting environment and health. In 2011, the Australian transport sector accounted for up to 16% of total greenhouse gas emissions [1], with the majority of these emissions being produced by internal combustion engine (ICE) based vehicles. As a result, there is an increasing thrust by the government towards increasing the uptake of electric vehicles (EVs).

This has challenged researchers to develop methods to evaluate the impact of policies on the uptake of EVs. This would allow policymakers to conduct a sound cost benefit analysis and evaluate their policies. This paper uses a system dynamic approach to captures the life cycle of the vehicle, the impact of individual choice, advertising, word-of-mouth and other social interactions. Based on which key policies are identified, and then evaluated using a cost benefit analysis.

Literature Review

Modelling methods to predict consumer uptake of alternative fuel vehicles (AFVs), can be broadly classified as: product diffusion modelling, discrete choice modelling, and a systems dynamics approach.

Diffusion models were used as early as the late 50's by Tanner [2] who developed a logistic model in the UK to forecast long term vehicle ownership. The more main stream theoretical foundations for diffusion modelling were set by Bass [3], who developed the widely used Bass Model. The basic principles lie in the theories of adoption and diffusion within social systems, and identifying two types of consumers – innovators (first adopters) and imitators (early adopters, majority and laggards); through which the demand of a new product can be estimated. Over the last several years, these family of models were further refined [4, 5, 6, 7; 8, 9, 10] and used to predict EV uptake in countries like the United States [11], Australia [12] and Korea [13]. Though these models have been useful in providing final estimates, it is agnostic about the factors affecting the process of diffusion, therefore not allowing for the possibility to test policies that might affect the diffusion process, such as increased exposure to certain type of vehicles.

The mainstay of research has focussed on the use of discrete choice models to model preferences over vehicles. Most of these models are conducted based on stated or revealed preference surveys. Brownstone et al. (2000) [14] used stated and revealed preferences with multinomial and mixed logit models to model vehicle choices. There have been several other studies that have modelled vehicle choice in this framework, either including different types of attributes or studying behaviour in different types of geographical regions (15, 16, 17, 18, 19, 20). In general, personal, vehicle and travel attributes were found to affect people's preferences over an EV, ICE or plug-in hybrid vehicle (PIHV). Though these models provide a depth of information on consumer behaviour, they are unable to capture the temporal and social dynamics of vehicle choices. In addition, it is also possible to evaluate policies that were included in the discrete choice model.

A system dynamic approach models the dynamical processes and choices, it takes into account temporal impact of policies, infrastructure and their feedback effects. In our review of EV models it seems that a systems dynamic approach best meets the needs of such a complex market space as Sydney. The dynamical approaches can be classified as agent based and macro models. The agent based models [21, 22] rely on game theoretic model [23] and stochastically simulate spatial interactions and behaviours of heterogeneous autonomous agents to study the emergent dynamical system at a spatial and temporal scale. These models are extremely complex and require a large amount of spatio and temporal individual level data to calibrate and validate these models.

This paper demonstrates the use of a systems dynamics model proposed by Struben and Sterman (2008) [24] to predict the market share of EVs. Recently, Shepherd et al. (2012) [25] used this model to evaluate the impact of advertising on the uptake of EV in the United Kingdom. The major contribution of this paper is the integration of a discrete choice model with the system dynamic model [24] to identify policies using a sensitivity analysis, and then conducting a cost benefit analysis to evaluate these policies. It is envisioned that this work would provide a framework for policymakers to evaluate uptake of EVs or the general uptake of a new vehicle technologies.

Modelling Approach

The model proposed by Struben and Sterman (2008) [24] (Referred to as Struben-Sterman model), is a dynamic model of diffusion of Alternative Fuel Vehicles (AFV). It is comprehensive in nature as it considers the whole product lifecycle, as well as accounts for feedback within the system. The model derives its formulation from incorporating and integrating a broad range of factors which are: a vehicle's characteristics, driver experience, social exposure, R&D of EVs, innovation spill over from other vehicle platforms, and development of fuelling infrastructure.

Feedback mechanisms which occur within the model are applied to model: social exposure, R&D of EVs, innovation spill over from other vehicle platforms, and development of fuelling infrastructure. These factors generate either a positive or negative feedback depending on scenarios. It is these feedback loops of the many factors which make this model comprehensive in forecasting a realistic prediction of future uptake of AFVs. The social exposure mechanisms of AFVs are broken down into three categories: marketing campaigns and subsidies, word of mouth from contact with AFV drivers and word of mouth from non-AFV drivers. The model represents the exposure mechanism as a weighted sum of these three categories. The exposure mechanism is used to derive the willingness of consumers to consider purchasing an AFV. The model also realistically predicts the possibility of decay of AFVs over time, due to consumer's lack of willingness to consider a product they do not have exposure to. The exposure mechanism model from this paper is similar in principle to Bass's product diffusion model, with Word of Mouth (WoM). An overview of the model is presented in Figure 1. These characteristics make the Struben-Sterman model the most ideal to evaluate policy impact on long term uptake of EVs. This research evaluates the uptake of EVs in Sydney from 2012-2030.

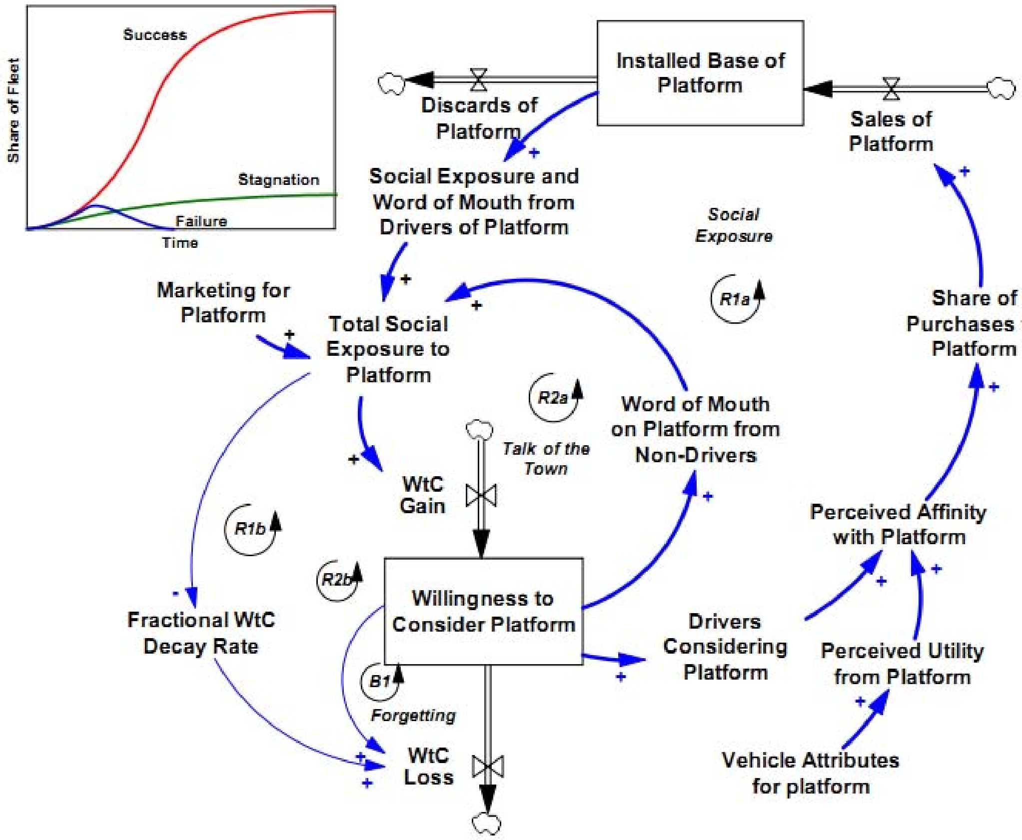


Figure 1: Factors influencing consumer choice of a platform (Struben and Sterman, 2008)

Figure 2 provides the schematics of the formulations and interactions which occur within the system. The installed base considers the life cycle of vehicles to predict their turnover rate and new demand for vehicles. A standard multinomial logit choice model was used to determine the share of purchases (σij) of a new platform (*i*) in the presence of an existing platform (*j*). This has inputs of perceived affinity with the platform, which is dependent on the driver's familiarity with the platform. Drivers must be sufficiently familiar with the platform in order for it to enter their consideration. Willingness to consider (WtC) increases in response to social exposure, and also decays over time. In this model, WtC for ICE was assumed to be 1, since ICEs are highly prevalent in our society. Total exposure to a platform typically includes: marketing, word-of-mouth between drivers of that platform, and word of mouth between those driving the platform and those not driving it. The word of mouth component of the social exposure of EVs was estimated as the strength of word of mouth for EVs multiplied by the ratio of EVs to the total number of vehicles. Further details of the formulation are provided in Struben and Sterman [24].

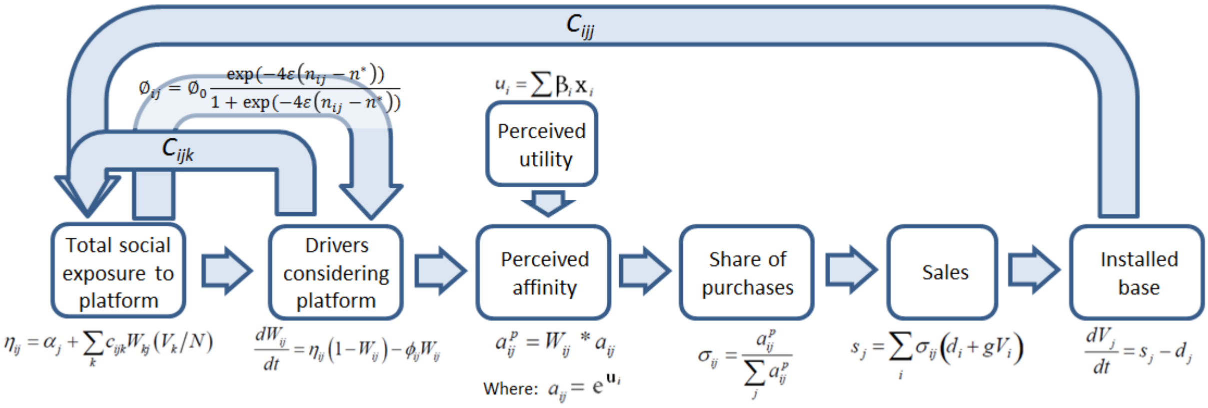


Figure 2: Schematics and Equations for Struben-Sterman System Dynamics Model

Parameters and Variables for Choice Model

The perceived utility of the vehicle is determined by the vehicle characteristics and other incentives in the system. Values for characteristics are obtained from multiple sources (stated in Table 1), and cover the Sydney demographic. The parameters for the utility function estimated in Brownstone et al. (2000) [14] were used in this study. It was seen as an appropriate source for these values due to California's similarity with the Sydney demography. Brownstone et al (2000) [14] study covered 79 areas which encompassed most of urbanised California, a similar urbanised demographic area for which the model of Sydney is to be based. Approximately 85% of residents in Sydney owned at least one car (City of Sydney, 2006)[26]; this is similar to the Brownstone et al (2000)[14] paper in which 80% of households had at least one car owner. Both the Sydney area and California area are characterised and orientated towards being very 'personal car' driven rather than the use of public transport. For these reasons we deemed it suitable to use the values from the Brownstone et al, (2000) [14] paper for our model of Sydney.

Table 1: Current values for characteristics for ICEs and EVs

Variable	Source	Characteristics	
		ICE	EV
Price/ln(income)[1]	DECC, 2009 [28]; City of Sydney, 2012 [26]	8.72	16.16
Operation cost (c/mile)[2]	DECC, 2009 [28]; Shepherd et al., 2012 [25]	21.83	4.02
Top speed (hundred miles/hr)[3]	Shepherd et al., 2012 [25]	1.25	0.76
Range (hundred miles)[4]	Shepherd et al., 2012 [25]	3.5	0.99
Pollution (1995 equivalent)[5]	Faias et al. [29]	0.999	0
Station Availability[6]	Charge Point Australia [30]; Motormouth [31]	0.992	0.0085

[1] Purchase price in thousands of dollars, divided by the natural log of household income in thousands. Average household income was $37,500.
[2] Operational cost is the fuel cost per mile of travel, in cents per mile. For electric vehicles, cost is for home recharging. For other vehicles, cost is for station refueling.
[3] Top speed is the highest speed that the vehicle can attain, in hundreds of miles per hour.
[4] Range is the hundreds of miles that the vehicle can travel between refueling/recharging.
[5] Pollution is the tailpipe emissions as fraction of comparable 1995 new gas vehicle.
[6] Fraction of stations capable of refueling/recharging the vehicle

Trends for each characteristic for ICEs and EVs were determined from the data presented in the Economic Viability of Electric Vehicles Report [28]. Top speed and range of vehicles with an internal combustion engine were assumed to not change significantly.

The total number of cars estimated to be in Sydney was found to be 2 786 892. Based on current data (RTA, 2010; ABS, 2011) electric vehicles (and plug in hybrids) were assumed to comprise of 0.0021% of the entire fleet. It was also assumed that everyone who discards an electric vehicle buys another electric vehicle. The growth rate of cars in Sydney was based on trends illustrated in DECC, 2009 [28].

Parameters for the model have largely been sourced from Struben and Sterman (2008)[24] including: reference rate of social exposure (η*), slope of WtC decay rate (ε), maximum WtC loss rate (φo), AFV market effectiveness (α), strength of word of mouth contact between AFV and ICE (Cijj) and between ICE and ICE (Cijk). Parameters of the Utility Function (B) have been taken from Brownstone et al. (2000)[14] and vehicle lifetime (L) of 10 years from ABS (2011)[27].

Sensitivity Analysis

To determine effective policies, a sensitivity analysis was conducted across the various variables in the utility function of the choice model, to evaluate the EV uptake. All parameters analysed have been presented in Table 2 which compares the proportion increase from the base case, a value of greater than one implies an increase in EV uptake.

Table 2: Sensitivity analysis of variable parameters, showing the proportion of Evs predicted in 2030, for variables not yielding a value of 1.

	-10%	-1%	Base	1%	10%
Price/Income	1.944824	1.066758	1	0.937809	0.532941
Operating cost	1.114652	1.010244	1	0.988515	0.896806
Top speed	0.947692	0.994631	1	1.0054	1.055453
Range	0.870993	0.986214	1	1.013996	1.149986
Pollution	NA	NA	1	NA	NA
Sation av.	1	1	1	1	1

Figure 3 shows the total number of EVs in the network in 2030. The most sensitive parameters were found to be: Price/lncome, Operating cost, range and top speed. Based on this it was decided that policies affecting Price/Income and Operating Costs would provide the most impact. The next section discusses and identifies the policies.

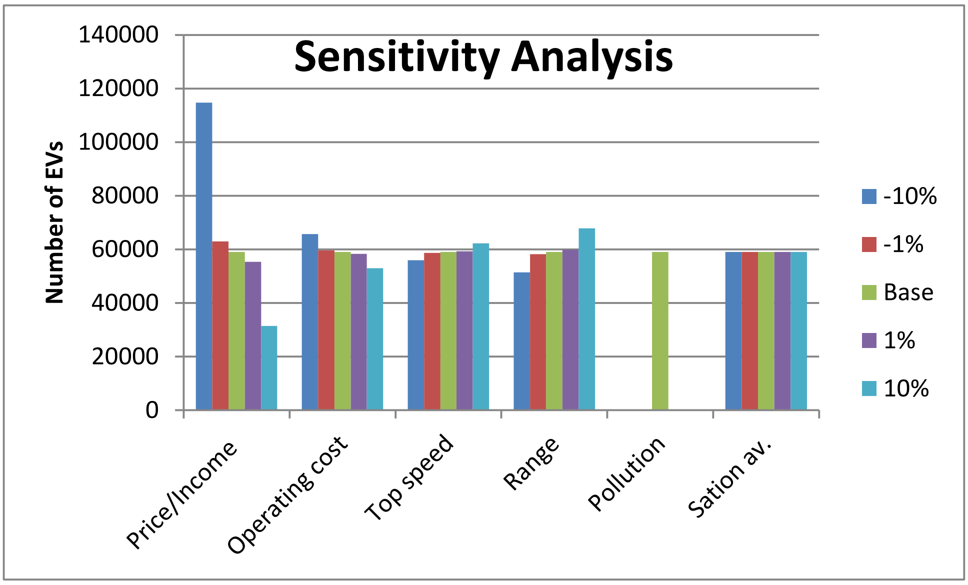


Figure 3: Key findings of sensitivity analysis.

Policy Recommendations

Governments worldwide are developing policies to promote and encourage the uptake of EVs. Some policies are being implemented to support the industry (development of the technology and appropriate infrastructure associated with EVs),i.e., affect supply, whilst others aim to increase EV demand. Many countries have a mixture of supply and demand policies. These policies only have the capabilities of manipulating the capital and operational cost price parameters.

Support to the Supply-side of the EV market

Supporting manufacturers and the supply-side of the electric vehicle market is one critical factor in the success of EVs within the Sydney market. Not only this, but with government support, the introduction of EVs not only has positive impacts on the environment, but can also have many flow-on advantages for the national economy, including job creation, and increasing GDP. Supply-side policies include introducing government funded programs aimed at developing the technology associated with EVs, primarily battery development. Along with this, there is also need for increased consumer awareness. This is done through EV transportation demonstrations. Worldwide there are initiatives to improve and increase the delivery of EVs. In 2009, the US announced the launch of two policy programs worth approximately $2.4 billion (USD). This included development grants and the construction of charging stations. Similarly in Portugal and the UK, the governments have committed to develop and provide charging stations for EVs [28].

Support to the Demand-side of the EV market

In addition to supply-side incentives, demand-side support must also be incorporated so as to co-ordinate the uptake of EVs within Australia. Many international governments were also offering incentives such as subsidies or financial assistance when purchasing an EV. The US had been offered tax credits varying from $2,500 to $7,500 (USD) depending on the capacity of the battery. Similarly, the UK offered financial assistance in the range of £2,000 to £5,000 when purchasing an EV or PIHV. Along with these subsidies there are other incentives for drivers of EVs such as free or reduced parking fees, and congestion charge exemptions. In Denmark, the government offered consumers the option of waiving the 180% vehicle purchase tax for EVs [28].

It is important to consider all possibilities and all policies in order to determine which one(s) are suitable for the intended country. All policies might not be viable or applicable to the Australian market, but adaptations must be considered. For Australia, the limited supply of EV might have a negative effect on the demand of EV uptake. Currently there is minimal infrastructure, such as charging stations, in the Sydney area. This is a major factor limiting the uptake of EVs within the region.

Other governmental policies may also have a negative impact on the uptake of EVs. The new carbon pricing mechanism (carbon tax) is one policy that has the potential to deter new consumers from purchasing an electric vehicle. Electricity prices are predicted to increase by 21% in NSW over the next year (Robins, 2012 [32]), and with the current limited battery-charging infrastructure in the region means that EVs will need to be charged at home, significantly increasing the homeowner's electricity bill. Implementing a reduced electricity rate of 25% for EV owners is one option that could help overcome this potential problem.

The subsidy or financial assistance and the free or reduced parking incentives have the most potential to persuade consumers into the EV market. Generally electric or hybrid vehicles are more expensive than standard combustion engines. Introducing these subsidies, electric/hybrid vehicles become more affordable to a larger number of household budgets. Introducing a biannual payment of $500 for 5 years to households with EVs, or offering other incentives such as reduced parking fees, tolls and/or making available EV-only parking spaces are other policies that could be implemented for those who have bought EVs to help boost EV uptake.

Based on the philosophy of affecting the supply side and demand side of EVs, and the sensitivity analysis, five policies were evaluated in this study. Each of the five policies incorporated five different levels of varying performance. These policies are:

<u>Policy 1 (P1)</u>: Free Charging – This policy allows free charging at public charge points only, for which the costs are paid for by the Government. For the purpose of modelling, all 5 levels of this policy have a 100% reduction in operational cost, which makes the conservative assumption that all drivers of EVs will only charge at these free charge points.

<u>Policy 2 (P2)</u>: Electricity Reduction – Similar to policy 1, this policy offers reduced operational cost through owners of an EV receiving subsidy on their electricity consumption for charging the vehicles. Across the five levels, the electricity subsidy ranged from 30% up to 70%.

<u>Policy 3 (P3)</u>: Research and Development – An investment by the Government ranging from $1 billion up to $5 billion (AUD), is applied for the duration of the study (2012-2030). This investment is for research into EV batteries which results in a reduction in the manufacturing cost and therefore the capital cost. Based on literature [33], a 3 billion dollar investment over

the analysis period (2012-2030) decreases the battery cost by $3200; this reduction is assumed to be spread linearly over the study period resulting in a reduction of approximately $178 per annum.

Policy 4 (P4): Tax Rebate – this produces a reduction in capital costs of an EV though owners receiving a tax rebate in the year that the purchase is made. Over the 5 levels the tax rebate varies from 30% up to 70%.

Policy 5 (P5): Station Availability – This policy is aimed at increasing the number of charging stations that are available to the public. The Government is modelled to pay for the capital cost of the charge point however not the cost of the electricity for charging. The total numbers of stations installed annually by the Government has been modelled at starting from 10 charge stations for level one and increasing to 50 for level 5.

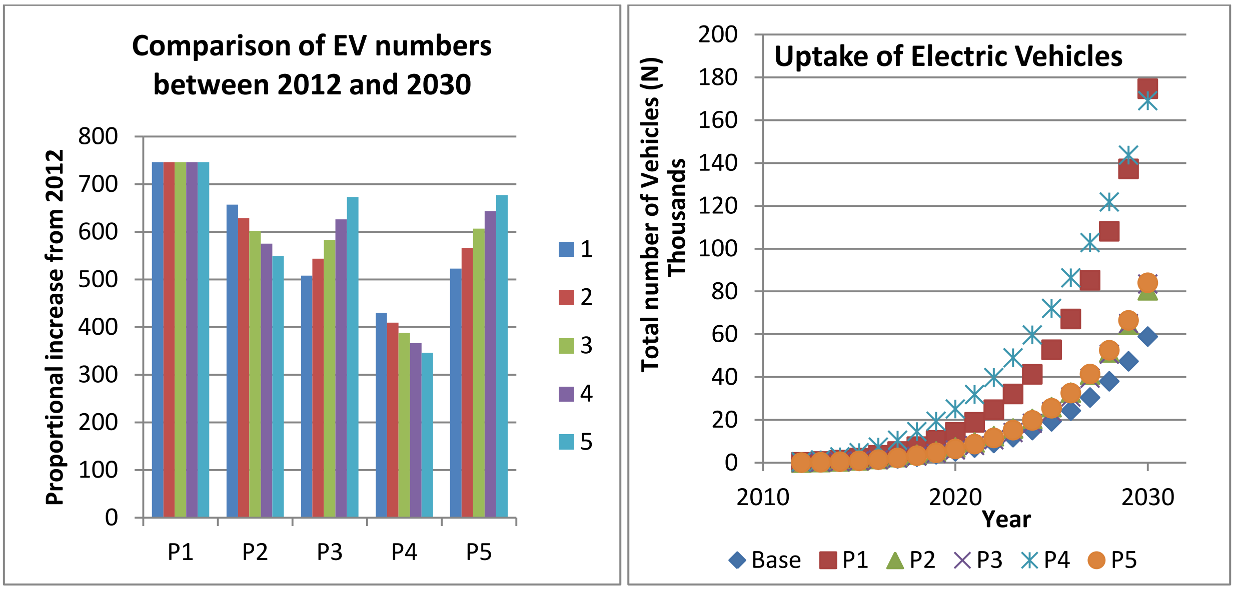
These various policy recommendations only have impacts on the perceived utility of the vehicle through changing the average capital price of EVs, the operational costs or the station availability. Five levels for each policy were applied in turn to determine the efficient case for each policy. Table 3 below summarises the type of policies evaluated in this study and the different levels of effects.

Table 3: Different policy options (L1-L5) and the different levels of effects

Policy	Nb	Variable	Effect	L1	L2	L3	L4	L5
Free Charging	P1	Operation	% Reduction	100	100	100	100	100
Electricity reduction	P2	Operation	% Subsidy	70	60	50	40	30
Research	P3	Capital	Investment $B	1	2	3	4	5
Tax rebate	P4	Capital	% Rebate	70	60	50	40	30
Charge stations	P5	Station Av.	Number of stations	10	20	30	40	50

Results

As expected it was found that the EV uptake increased with the level of support and investment (Figure 5a). Due to this the annual trend in uptake of electric vehicles for the highest level of support was considered, and is shown in Figure 5b. Further, all policies were found to increase the EV uptake, and almost has an exponentially increasing trend. It was found that with policy 1 that provides Free Charging and Policy 2 which provides a tax rebate had the most significant impact.



(a) **(b)**

Figure 5: (a) Comparison of EV uptake between the five policies; (b) Uptake of electric vehicles for level 5

Cost Benefit Analysis

Cost Benefit Analysis (CBA) enables decision makers to weigh the advantages and disadvantages of a project in monetary terms (Harding, 1998) [34]. This sections aims to assess the social, environmental and economic costs and benefits of each of the five policy options. Based on Harding (1998) [34], the following steps were conducted in the CBA.

Identify the policy

The aims of these policies are to increase the uptake of EVs within the Sydney region. As the population of Sydney continues to increase, facilitating the increase in the number of cars registered in Sydney, pollution levels across the State will rise and air quality will decrease. The introduction of plug-in EVs into the Sydney market has the potential to reduce the impact of pollution due to personal transport vehicles, as well as contribute to Australia's national target of reducing at least 5% of its 2000 carbon emission levels by 2020.

Impacts and Effects

According to the government viewpoint, the costs and benefits of each policy would be similar, with only their magnitudes changing for each subsequent policy. The costs for the policies included: Building and installing charging stations; forfeiting of tax revenue; expenses to subsidise electricity; education, advertisement and public relations costs; and administration cost.

The benefits identified from the governmental perspective were: Environmental Benefits; and increased revenue streams from registration fees for EVs, tax revenue from car sales and tax revenue from increased electricity sales due to EV uptake. The monetary values of each cost and benefit are shown in Table 4 and 5 respectively.

Table 4: Justification and Sources used to Identify Costs for the CBA

Description	Justification and Sources
Expense to subsidise electricity	• Every EV travels an average of 38km per day (My Electric Car, 2012), • It takes approximately 14kWh to travel 100km in an electric vehicle (My Electric Car, 2012),i.e. the full battery for an EV. • Each battery is one-thrid full when charging is initiated. Therefore, 9.38kWh is required to charge each battery to full range.
Education, advertisement and public relations costs	• 1% of the NSW Government's non-campaign advertising budget is used to promote the policy to the public • In the subsequent years, the advertising budget reduces to 0.5% until the number of EVs in the market reaches 15,000 • Once the EVs reach a penetration level of 15,000 vehicles, it is believed that word-of-mouth and existing internet sites and campaigns are sufficient to provide NSW consumers with the information required to buy EVs and to access the policy. • According to the Auditor-General's Report on NSW Government Advertising (2009), the non-campaign advertising expenditure was $30 million AUD in 2009.
Administration Costs	• In a study conducted by Wolfe and Brown (2006), they surveyed the administration costs of twelve policies that focussed on increasing energy efficiency, with a few policies involving fuel efficiency and EVs. The average administrative cost per kWh of energy saved is $0.18. To be conservative, the figure of $0.20 per kWh of energy saved will be utilised in this report. • According to the NSW Government (2012), every kWh of electricity produced in NSW produces 1.07kg of CO_2-equivalent gas, and the average tail-pipe emissions of a conventional ICE vehicle is 3,240 kg CO_2 per year (Australian Government Department of Sustainability, Environment, Water, Population and Communities, 2008).
Rebate expense	• The average weekly cost of electricity per household is $32.05 prior to the purchase of an electric vehicle (ABS, 2008). • Every EV travels 38km per day (My Electric Vehicle, 2012) and must be re-charged every third day • A fully charged car has a range of 100km. • The average cost of electricity is $0.18 per kWh and it takes approximately 14kWh to travel 100km (My Electric Car, 2012). • The average number of vehicles per household is 1.6 (ABS, 2008).
Forfeit of tax revenue due to rebate	• The NSW Government funds a certain percentage of the difference between purchasing a conventional ICE vehicle and an EV.
Expenses incurred subsidising electricity bills	• Private charge companies construct their own charging stations • To aid in market penetration of EVs, the NSW Government will commit to constructing a certain number of new charge points annually • Charging from the Government-owned charge points will not be free to access • Each charge point costs $6,000 to construct [28].

Table 5: Benefits for the CBA

Description	Justification and Sources
Increased revenue from registration fees	The average price to register a car in NSW is $324 per car (RMS, 2011).
Increased tax revenue from car sales (stamp duty)	The price of EVs was modelled in this report and used to calculate the average stamp duty received by the NSW government due to the sale of EVs. In NSW, stamp duty is calculated at 3% for cars up to $45,000 and a further 5% for every dollar above $45,000 (Private Fleet, 2012).
Revenue from Sales Tax earned from electricity sales	In Australia, the Goods and Services Tax (GST) is 10%. It is assumed that the average price of electricity is $0.18 per kWh.
Environmental benefits	The current carbon price is $23 per tonne of CO_2 (Australian Government, 2012), and the environmental benefits were calculated using this price and the modelled pollution 'savings' acquired when EVs are used instead of ICE vehicles.

Discount Rate

The discount rate was determined by first establishing a lower bound discount rate. When evaluating risk-less projects, the risk-free interest rate should be used. This is the minimum return the project should yield if the project is riskless. As the policy alternatives involve inherent risk, this discount rate can only be used as a lower bound. The current Australian risk-free interest rate is 3.5% (Trading Economics, 2012)[35].

The second step involved establishing a higher bound discount rate. According to Harding (1998)[34], a high discount rate can be considered as 10% p.a. Taking a higher discount rate is not recommended, as Harding believes that using a higher discount rate undervalues the costs and benefits of today's actions on future generations. Due to this, 10% will be used as an upper bound. The average of the upper and lower bound was then utilised to determine the discount rate, r=6.75%.

Net Present Value (NPV)

The NPV is calculated using the following formula:

$$NPV = \sum_{i=0}^{n} \left(\frac{V_i}{(1+r)^i} \right)$$

Where:

V_i = value of cost of benefit occurring in year i

r = discount rate = 6.75% p.a.

n = policy life = 19 years

The results for each policy are shown in Table 7. Policy 2 level 1, i.e. government providing 70% subsidy on electricity cost for charging EVs was found to be the most cost effective.

Table 6: Cost and Benefit of each Policy in NPV ($million AUD)

Policy	Policy Level				
	L1	L2	L3	L4	L5
Policy One	$41.80	$41.80	$41.80	$41.80	$41.80
Policy Two	$61.70	$59.00	$56.29	$53.48	$50.80
Policy Three	-$688.90	-$1,416.00	-$2,143.00	-$2,870.00	-$3,596.00
Policy Four	-$175.21	-$173.99	-$164.64	-$142.99	-$103.10
Policy Five	$40.30	$42.70	$44.90	$46.80	$48.60

Discussion

In modelling EV uptake it has been found that all policies register a net increase in EV uptake. The greatest uptake is from Policy One, free EV charging, with 174, 379 EVs and the lowest being Policy Three, investment into EV development, with an uptake of 63 061 EVs. In performing our CBA it has been found that policy benefit is dependent upon the level of implementation. In low level implementation, Levels One to Three, we find that Policy Two, subsidising household electricity, is the most cost beneficial to government. However with higher levels of implementation, we find that Policy Five, building extra charge stations, performs equally as well as Policy Two, and at Level Five implementation Policy Five outperforms all other policies in terms of cost benefit.

Policy One, free charging, encourages the greatest uptake of EVs numbering 174 739 EVs. Policy One also returns a positive cost benefit of $239.40 (AUD) per an EV. This is the lowest positive net benefit amount amongst the policies implemented from Levels 2 to 4. Although Policy One is the lowest positive cost benefit amount, implementation of Policy One gives the highest EV uptake of 174 739.

Policy Two, household electricity subsidies, gives a maximum uptake of 124 260 EVs. At Level Five, implementation of Policy Two has the lowest uptake of EVs numbering only 80 954. However, Policy Two is shown to be the most beneficial policy in our CBA across Levels 1 to 3. The net benefits of Policy Two amount from $50.80 million (AUD), at Level 5, to $61.7 million (AUD), at Level 1. In Policy Two it is shown that the higher the electricity rebate the higher the cost benefit amount. This can be explained with cost to government being lower as well as environmental impacts being lessened with lower rebates. The gross cost per an EV in Policy Two is also found to be cheaper than Policy One, free EV charging, costing $115.01 (AUD). Policy Two does not promote a rate of EV uptake as great as Policy One. However, the cost to benefit is greatest across all levels up to Level 4 and as such we believe this to be the most beneficial policy to EV uptake.

Policy Three, investment into EV technology, gives the lowest EV uptake with only 83 530 EVs at Level Five implementation. Policy Three retains the lowest EV uptake throughout all levels of implementation compared to the other policies. Policy Three is in fact three years behind Policy One and, in terms of costs, is over 40 times the amount of Policy One. Within the CBA, Policy Three and Policy Four both give negative amounts. Policy Three gives the smallest return of all the policies. Even at Level One a loss of over $688.9 million (AUD) is incurred in the years up to 2030. Increasing the degree of Policy Three does not show any sign in creating a positive result, the relation depreciating linearly up to a total amount of $3.6 billion(AUD). It is clear that Policy Three is the most expensive policy with the lowest cost benefit and lowest EV uptake.

Policy Four, a diminishing tax rebate, has a maximum uptake of 169 170 EVs. This rates Policy Four as the second most effective policy for EV uptake by a margin of approximately 5 600 EVs. Although this is a good result, the CBA of Policy Four returns a negative result. Even at a tax rebate of 70%, Level One, a negative amount of $175.21 million (AUD) is incurred; increasing the degree up to Level 5, a 30% tax rebate, a loss of $103.1 million (AUD) is incurred. Thus, Policy Four can be seen as an expensive yet effective policy to encourage EV uptake.

Policy Five, building infrastructure, is a low performing policy for EV uptake, but the highest cost benefit at level five implementation. Policy Five is the cheapest gross cost per an EV of all the policies across all levels of implementation. Level five implementation of 50 charge points costs $71.22 (AUD) per an EV. This is the cheapest option, but not the most cost beneficial for implementation levels below 5. Though Policy Five contributes the greatest cost benefit, it ranks poorly in EV uptake.

The results suggest that government policies that deal directly with consumers instead of manufacturers and retailers are the most effective in gaining EV uptake. This is shown in Policy One registering the highest EV uptake. The nature of Policy One deals directly with consumers and at an everyday level giving the greatest frequency of accessing the policy benefit. This is also seen in Policy Two a policy that deals directly with consumers and at an everyday level, paying electricity bills. Policy Five also has frequent interaction between consumer and the policy infrastructure. These policies show greatest cost benefit and in Policy One this translates to having the highest EV uptake. Policies that offer benefits frequently as opposed to one off payments may also increase EV exposure, a reason why Policy One, Two and Five do well in the CBA.

Conclusion

In the Sydney case study, it was found that government subsidises of 70% on electricity used to charge EVs, would provide the most cost effective method to increase uptake of EVs. As the CBA not only takes into account the revenues and expenses incurred by each policy, but also the environmental benefit gained from the modelled number of EV adopted by each policy, it represents a thorough weighting of each cost and benefit to the government.

This research presents a framework to evaluate policies that promote the uptake of Electric Vehicles and conduct a holistic cost benefit analysis. The research adapted the system dynamic Struben-Sterman model to predict impact of social interactions and the number of vehicles in the system. This model provided one of the most comprehensive macro level framework to evaluate future uptake of electric vehicles. This was integrated with a discrete choice model to predict the consumer choice of people purchasing vehicle.

Several policies were identified based on sensitivity analysis, and factors that were found to have the maximum sensitivity were targeted through policies. Finally, these policies were evaluated using a comprehensive CBA, which collated parameters and variables through extensive research. It is expected that such a framework can be easily used and implemented by transportation planners and policy makers to evaluate the impact of policies. There is also significant research that needs to be conducted to account for risk in these forecasting models.

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