Zero Carbon Australia

Electric Vehicles

beyond ZERO emissions

MRCagney

Zero Carbon Australia

Electric Vehicles

Beyond Zero Emissions

As the minister responsible for climate change policy, I am excited by the prospect of zero carbon cars and consider electric vehicles as an important technology for reducing transport sector carbon pollution.

-Hon Dr Steven Miles, MP

Minister for Environment and Heritage Protection and Minister for National Parks and the Great Barrier Reef, Queensland Government.

At BMW, we see that electric mobility is the trend in the automotive industry and that is why we have invested heavily in the new technology and even created a new sub-brand around electric mobility with BMW i. The driving forces for us to invest in electric mobility have been changing values in customer expectations, cultural changes to a more sustainable mobility as part of a modern urban lifestyle, urbanisation with an increasing population living in cities as well as climate change, with the subsequent effects. These changes can also be seen in CO2 and fleet regulations in many countries around the world where zero emission vehicles will play an important role to meet these regulations.

-Alexander Brockhoff

BMW Group Australia

This is an exciting time in Australian automotive history. A step that will one day be celebrated by our enthusiast community. Our proud history is the learning foundation we take with us into this new technology advancement. We must never stop striving to advance our vehicles, always mindful that the greatest challenge will be educating our nation of drivers on how to safely drive them and realise their full benefits.

-Peter Styles

Australian Motoring Enthusiasts Party

Climate change represents a significant challenge for Australia and also an opportunity to leverage our innate capacities to solve. Australia has a well educated work force, world class universities and CSIRO. As Australia and the world transition from traditional forms of energy to low carbon emissions forms, we need to ensure that our workforce is similarly transitioned to manufacture the products needed to solve climate change.

Electric vehicles, battery storage, wind and solar products can all be made in Australia, creating thousands of high quality manufacturing jobs and building a sizeable export program to countries that want our high-performing and dependable renewable energy products. The work of Beyond Zero Emissions in producing the Zero Carbon Australia Electric Vehicles Report is a significant body of work that will lift our understanding of the urgent need to engage in this work for the future of our environment and for working communities across Australia.

-Richard Inwood,

Nick Xenophon Team

The shift to electric vehicles is an absolute 'no brainer'. The technology is already here, rapidly improving and increasingly affordable. Electric vehicles provide tangible, direct benefits for the individual, the community and the planet. Governments at all levels need to start showing leadership and stop dragging their heels. Noosa's current (excuse the pun) electric bus trial is just the beginning of the transport revolution in our local government area.

-Tony Wellington

Mayor, Noosa Council

The Australian Electric Vehicle Association (AEVA) is pleased to see the hard work of Beyond Zero Emissions come to fruition, with this Zero Carbon Australia Electric Vehicles Report being released. The AEVA, formed during the oil price shocks of 1973, has long held the view that a shift to zero emission electrified transport is inevitable. Electric vehicles are quiet, low-maintenance and extraordinarily energy efficient. Land transport is currently the second largest source of greenhouse gas emissions in Australia, with most of the fuel being imported from overseas. Making the switch to battery electric vehicles for private and public transport makes sense both environmentally and economically. The information contained in this report reinforces and builds on what the AEVA has advocated for decades - that electric vehicles will make for a cleaner, safer, and more economically prosperous nation. I commend BZE for their dedication and attention to detail in this report, and I trust that our leaders and policy makers will heed the advice contained herein.

-Dr Chris Jones

Vice President and Assistant Secretary of the Australian Electric Vehicle Association (AEVA).

This ambitious, credible, exciting report sets out a clear choice for Australia. Either we can seize the opportunities of clean transport, improve our quality of life and even save money, or we can stick with the dangerous course we're currently on.

We can and must dramatically cut pollution from every sector of our economy, and by doing so we can create a better future for our children. Beyond Zero Emissions have consistently led the way articulating a positive, hopeful plan for Australia's future, and it's time for governments to follow that leadership.

-Senator Larissa Waters

Deputy Leader Australian Green Party

Communities that embrace the inevitability and desirability of early electric vehicle adoption by providing charging stations and parking provision will be communities that help re-navigate the world onto a sustainable and honourable path. They will be the communities that surf the wave of change and gain the most benefits from doing so. Research such as that contained within this report will embolden smart, innovative and inspired communities to view this change as an opportunity rather than an inconvenience and exclaim proudly, 'Viva EV!'

-Cr. Simon Richardson

Mayor, Byron Shire Council

Due to the outlook for rising global environmental awareness, electric-powered vehicles are expected to see increased demand in the future with their outstanding environmental performance.

Mitsubishi Motors introduced the world's first mass-produced electric vehicle and has a long history of EV technology. Based on these strengths, Mitsubishi Motors positions electric-powered vehicles along with SUVs as its core products. Mitsubishi Motors will continue to develop technology that responds to challenges being currently faced, social challenges expected in the future, and fully incorporates the values customers demand. Mitsubishi will continue to provide vehicles that deliver driving pleasure and reassuring safety while manufacturing vehicles that excite customers.

-Craig Norris

Mitsubishi Motors Australia Limited

I am delighted that the transition to electric vehicles is finally gaining genuine and sustainable momentum, after decades of having been opposed and undermined by the oil and auto industries. Australia is well placed to help drive this revolution with the development of pure natural graphite that will enhance the efficiency of battery storage and lower its cost considerably.

-Dr John Hewson

Professor Crawford School ANU and former Opposition Leader

Our mission at Tesla is to accelerate the world's transition to sustainable energy. A major part of our mission is the production and delivery of sustainable transport, with our plan to bring a range of increasingly affordable electric vehicles to market. Tesla has delivered more than 100,000 electric vehicles to customers worldwide to date, with Australia a key part to our continued growth.

Tesla also has developed its own infrastructure network with the provision of home charging, Supercharging for long distance travel and Destination Charging at key locations. This, along with our vehicles, makes electric vehicle ownership a no compromise, compelling offer in market.

-Heath Walker

Tesla

BZE have for years been the pathfinder, mapping the possibilities for our rapid, and inevitable, transition to a low-carbon society, work which the political and corporate elites have been too timid or conflicted to undertake. BZE are performing an essential service to the Australian community in filling the vacuum left by official myopia and short-termism. The Zero Carbon Australia Electric Vehicles Plan is another vital piece of the jigsaw we must complete to make that transition, but particularly important given the need to move away from our social and economic reliance on ICE technology in a large continent with a widely dispersed population.

-Ian Dunlop

Member of the Club of Rome

We at Brighsun congratulate the Beyond Zero Emissions team on their substantive work and insightful report. When our Touring eBus secured the Guinness World Record in late 2015 for 'Greatest distance travelled by an Electric Bus (non solar) on a single charge, 1018 km, we were taken aback at the level of interest generated from transport operators, consumers and Governments. We realised that as pure eVehicles become more affordably priced and are able to travel a commercially practical range on a single charge, then we are just at the start of an exciting revolution in how we travel within and between our cities - with associated massive cost savings and dramatic reduction in pollution. We see the leadership role of Government as key in introducing policies fostering the more rapid take up of eVehicles by both consumers and operators, for the benefit of us all..

-Charles Brent

CEO, Brighsun EBus Pty Ltd

The Zero Carbon Australia Project

The Zero Carbon Australia Project comprises six plans providing a detailed, costed and fully researched road map to a zero carbon economy for Australia. Following six guiding principles, each plan uses existing technology to find a solution for different sectors of the Australian economy. The ZCA guiding principles are:

1. Australia's energy is provided entirely from renewable sources at the end of the transition period.

2. All technology solutions used are from proven and scalable technology which is commercially available.

3. The security and reliability of Australia's energy is maintained or enhanced by the transition.

4. Food and water security are maintained or enhanced by the transition.

5. The high living standard currently enjoyed by Australians is maintained or enhanced by the transition.

6. Other environmental indices are maintained or enhanced by the transition.

Stationary Energy Plan

The plan details how a program of renewable energy construction and energy efficiency can meet the future energy needs of the Australian economy [1].

Buildings Plan

The plan outlines a practical approach to fixing Australia's buildings within a decade, showing we can act now to halve the energy use of our buildings, deliver energy freedom to people, and transform our homes and workplaces to provide greater comfort with lower energy bills [2].

Transport Plan

The plan will show how Australia could run a zero fossil fuel passenger and freight transport system. The main focus is on the large-scale roll-out of electric rail and road cars, with the application of sustainable bio-fuels where appropriate and necessary.

The Transport Plan is outlined in a series of reports. The High Speed Rail report proposes a High Speed Rail network connecting the major capital cities and regional centres along the Australian east coast corridor between Melbourne, Sydney and Brisbane [3].

This report on electric vehicles forms part of the Transport Plan, addressing the transition of personal urban car travel from fossil-fuelled to electric, operating on 100 per cent renewable electricity. Later reports will address public transport and freight.

Industrial Processes Plan

The plan will show how our industrial energy requirements can be supplied primarily from 100% renewables and investigate replacing fossil fuels with chemical equivalents.

Land Use, Forestry and Agriculture Plan

With a significant proportion of Australia's emissions from land-use change, forestry and agriculture, the plan addresses broader issues like land-use efficiency and competition for different uses of land for different purposes and products.

Renewable Energy Superpower Plan

This Plan highlights the enormous opportunities for Australia to leverage its natural advantages in solar and wind resources, and capture the billions of dollars being invested globally in renewables and energy efficiency over the next two decades.

Contents

You can help us produce climate solutions

Researching Zero Carbon solutions for Australia is a hard job.

The fact is that Beyond Zero Emissions relies on donations from hundreds of donors, both small and large. People like you. We don't get Government backing. We are very careful to ensure that our research is independent.

To do the research that needs to be done, to get the word out there, to empower Australians by providing them with scientifically sound facts, all costs money.

Your help will allow us to continue researching our Zero Carbon Australia solutions. And every cent helps.

Who are Beyond Zero Emissions?

Beyond Zero Emissions is a not-for-profit research & education organisation.

We are working to deliver a zero carbon Australia, relying on the support of people like you.

What is the Zero Carbon Australia project?

The Zero Carbon Australia (ZCA) project is an exciting initiative of Beyond Zero Emissions and the University of Melbourne's Energy Research Institute. The project is a road map for the transition to a decarbonised Australian economy.

The latest and most credible science tell us such a transition is necessary in order to reverse climate disruption.

The project draws on the enormous wealth of knowledge, experience and expertise within Beyond Zero Emissions and the community to develop a blueprint for a zero carbon future for Australia. There's more about the ZCA project on the back of this page.

How can you help?

Please tear out the donations form to the right, fill it in, seal the edges and send it to Beyond Zero Emissions, Suite 10, 288 Brunswick Street, Fitzroy, Vic 3065

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Centre for Energy and Environmental Markets

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Key Findings

1

1 Key Findings

This study analyses the transition to 100 per cent electric vehicles[1] in Australia, powered by 100 per cent renewable energy, over a ten year period. The key findings are:

- *A shift to 100 per cent electric vehicles would eliminate at least six per cent of Australia's greenhouse emissions.*

At present, approximately six per cent of Australia's greenhouse emissions are attributed to the operation of urban passenger vehicles. Shifting to 100 per cent electric vehicles (EVs), operating on renewable electricity, would eliminate these emissions. Up to 8 per cent of national emissions would be removed if regional passenger vehicles are also included. There would also be additional economic, health and environmental benefits from the transition to EVs, such as improved urban air quality, reduced noise pollution, increased urban amenity, reduced reliance on imported fuels and a reduction of approximately 500-1000 pollution related deaths in Australia per year from existing internal combustion engine vehicles.

- *Electric vehicles are more convenient.*

Electric vehicles already have the range to cover the majority of urban car trips. EV drivers often charge their car at home, meaning their car is usually fully charged and they avoid the inconvenience of filling their car at the petrol station. EVs will be even more convenient once we have comprehensive public charging infrastructure in urban areas, as assumed in this study, with the convenience of charging at work, at the shopping mall, and other public locations.

- *A rapid shift to electric vehicles operating on 100 per cent renewable electricity is both realistic and affordable.*

Electric vehicles are significantly cheaper to fuel and maintain. This significantly offsets the current higher purchase price of EVs. Applying conservative assumptions (which are likely to overestimate costs), the analysis in this report finds that it will cost approximately 25 per cent more than a business-as-usual scenario to transition to 100 per cent electric cars by 2025. This equates to $20 more per capita, per week.

If car and battery technology progresses at the more rapid end of projections, maintenance costs for electric vehicles are at the lower end of projections, and petrol prices are at the higher end of projections, then this analysis finds that a shift to 100 per cent electric cars in ten years could cost the same as the business as usual scenario. This means that under certain conditions there may be no additional cost to transition to 100 per cent electric cars in Australia by 2025.

- *Costs could be even lower if we adapt transport behaviours to reduce car ownership.*

Policies that make it more convenient for more Australians to use non-car transport modes, such as public transport, walking, cycling and other forms of electric personal mobility (such as bicycles and scooters), combined with increased access to car-share and ride-share schemes, will allow more Australians to avoid the costs of individual car ownership. This will reduce the costs of a shift to 100 per cent electric vehicles even further, and also make the scale

1 The term Electric Vehicles (EVs) is defined in this report as primarily passenger vehicles (cars less than 3.5 tonnes Gross Vehicle Mass) powered by 100 per cent (renewable) electricity. However a section of the report is dedicated to buses, as these present an excellent and cost-effective opportunity to transition rapidly to being powered by electricity.

of the task easier as there are less vehicles in the Australian passenger fleet required to transition to EVs. A shift towards increased use of public transport, walking and cycling also offers benefits in reducing traffic congestion, reducing traffic accidents, and increasing incidental exercise to promote improved health outcomes.

A rapid shift to electric buses operating on 100 per cent renewable electricity is also feasible, and affordable.

A shift to 100 per cent electric buses for all urban public bus transport in Australia is found to cost only 10 per cent more than business as usual. This amounts to an increase in cost of only $0.72 per capita per week. If bus and battery technology progresses at the more rapid end of projections, maintenance costs for electric buses are at the lower end of projections, and petrol prices are at the higher end of projections, then this analysis finds that a shift to 100 per cent electric buses in ten years could cost almost 12 per cent less than business as usual. This would mean that a transition to 100 per cent electric buses would be economically attractive.

Executive Summary

2 Executive Summary

The global electric vehicle revolution is rapidly following the transformation we have recently seen with rooftop solar and is closely tied to the battery revolution occurring at the same time. With prices of batteries projected to fall by between 20 and 60 per cent by 2020, this is a more spectacular drop than the 30 per cent drop in prices for photovoltaic panels that have been experienced over the last 5 years. The latest EVs being manufactured in both the US and Europe are substantially cheaper than earlier models, and have the added benefit of increased travel range as well.

Figure 1 – EV carshare, Paris France

This report shows that the shift to 100 per cent electric vehicles[2] in Australia is both feasible and affordable, and provides a range of environmental, health and other benefits to the economy. The analysis focuses on the transition to 100 per cent electric vehicles in Australia, operating on renewable energy, within ten years[3]. Car travel in Australia contributes 8 per cent of national greenhouse emissions [4], with around 75 per cent of those (or around 6 per cent of national greenhouse emissions) being attributed to urban travel. A transition to electric cars provides an opportunity to eliminate these greenhouse emissions.

Urban car travel is well suited to a transition to electric vehicles. Typical urban Australians have a daily driving distance of only 35km [5], with almost half of trips taken being less than 5km, and more than 99 per cent of trips being less than 120km, which is within the range of a relatively modest electric vehicle. It is expected that most drivers will take advantage of the convenience and low cost of charging their vehicle at home [6]. For the rare circumstances when longer journeys are required, or for EV users who don't have access to home charging, this modelling includes extensive public charging infrastructure. This includes rapid charging facilities throughout all urban areas in Australia, which allow a user to charge up to 80 per cent of their battery capacity in 30 minutes.

To quantify the costs and benefits of transitioning to a 100 per cent electric vehicle fleet by 2025, a

2 The term Electric Vehicle (EV) is defined in this report as passenger vehicles (cars less than 3.5 tonnes Gross Vehicle Mass) powered by 100% (renewable) electricity. However a section of the report is also dedicated to buses, as these present an excellent and cost-effective opportunity to transition rapidly to being powered by electricity.

3 This analysis focuses on personal car travel - freight and public transport are not included and will be addressed in upcoming BZE reports.

model was developed to calculate costs for two options:

- Option 1 - Business as Usual: In this option it was assumed that the Australian car fleet continues to be dominated by internal combustion engine (ICE) cars. The size and composition of the car fleet are assumed to continue to change in line with historical state-wide trends; and

- Option 2 - Technological Change: In this option it was assumed that from 2015, ICE cars are phased out, such that the Australian car fleet consists solely of electric cars by 2025. As for Option 1, the size and composition of the car fleet are assumed to change in line with historical trends. This transition is depicted in Figure 2.

Figure 3 provides a comparison of the total costs. With conservative assumptions (which are likely to overestimate the costs), total costs incurred in Option 1 (assuming continuing use of ICEs) are calculated to be $993 billion. This cost is calculated as a net present value of aggregate costs over the twenty year evaluation period from 2015 to 2035. The transition to 100 per cent electric cars is complete in ten years (by 2025), and the twenty year evaluation period is used to capture the benefits of lower fuel and maintenance costs in the post-transition period[4].

Costs are calculated to be 25 per cent higher in Option 2 with a shift to 100 per cent electric cars, operating on 100 per cent renewable electricity. The difference between the two options amounts to an increase in cost of $20 per capita per week to transition to 100 per cent electric cars, operating on 100 per cent renewable electricity.

In Option 1 (continuing to use ICEs) the majority of cost is found to be in car maintenance, with capital costs and fuel costs also being significant. In contrast, Option 2 has higher capital costs due to the replacement of the entire car fleet with electric cars within ten years. However, in Option 2 maintenance costs are significantly lower, and fuel costs are also reduced (electricity is less expensive than petrol, per kilometre travelled.)

Costs for each of these options were also calculated under a Low Cost Scenario, which makes a number of more optimistic assumptions:

1. Car and battery technology progress at the more rapid end of projections,

2. Maintenance costs for electric cars are at the lower end of projections, and

3. Petrol prices are at the higher end of projections.

Figure 4 illustrates the comparison of the total costs in the Low Cost Scenario. With these more optimistic assumptions, a shift to 100 per cent electric cars operating on 100 per cent renewable electricity is found to have an almost identical cost to continuing to use ICEs.

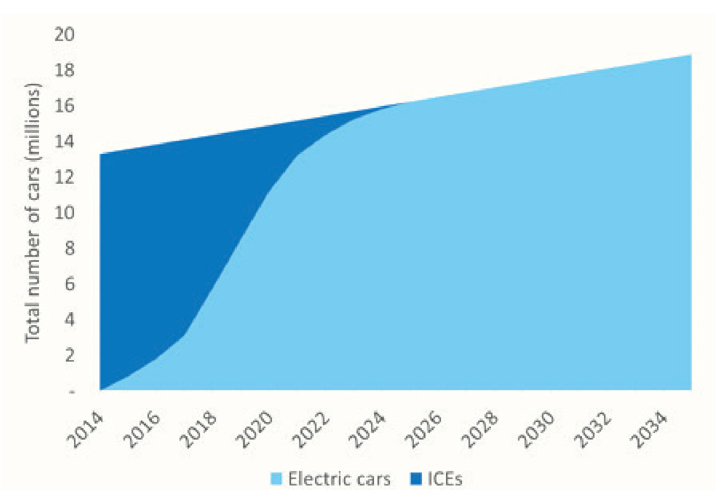


Figure 2 – The transition of Australia's car fleet from ICE cars to electric cars.

4 This modelling assumes a transition to 100 percent electric cars by 2025 (in ten years). The total costs of this transition are calculated over a twenty year evaluation period (2015 to 2035), to ensure that all the capital costs and operating costs are captured over the long term, with an 8 percent discount rate.

This indicates that if petrol prices are at the high end of projections, and electric car and battery technology costs reduce at the more rapid rates being projected, then a rapid to transition to 100 per cent electric cars operating on 100 per cent renewable electricity could cost no more than business as usual. This would eliminate six per cent of Australia's greenhouse emissions (the proportion currently attributed to urban cars) at no cost.

Figure 5 compares the greenhouse gas emissions from cars under two options. In Option 1 we continue to rely on ICEs and the fleet continues to expand in line with historical trends. In Option 2 we replace the entire ICE fleet by 2025 with EVs operating on 100 per cent renewable electricity. In Option 2, emissions rapidly decrease to zero by 2025, whereas with Option 1 greenhouse gas emissions continue to rise over time as the ICE car fleet expands in line with historical trends.

The costs of shifting to 100 per cent electric vehicles would be even lower if complementary policies are adopted to allow more Australians to conveniently walk, cycle, and use public transport, with simultaneous support for car-share and ride-share programs that provide the convenience of access to a car, while avoiding the costs of individual car ownership. These high-use applications are ideal for electric vehicle technology, and their uptake would reduce the cost of an electric vehicle transition.

Electric buses were modelled in a similar manner to electric cars, exploring the conversion of urban bus fleets in cities around Australia to electric. With conservative assumptions, the electric bus model indicates that a shift to 100 per cent electric buses would cost around 10 per cent more than business as usual. This amounts to an increase in cost of only $0.72 per capita per week. With more optimistic assumptions, it is found

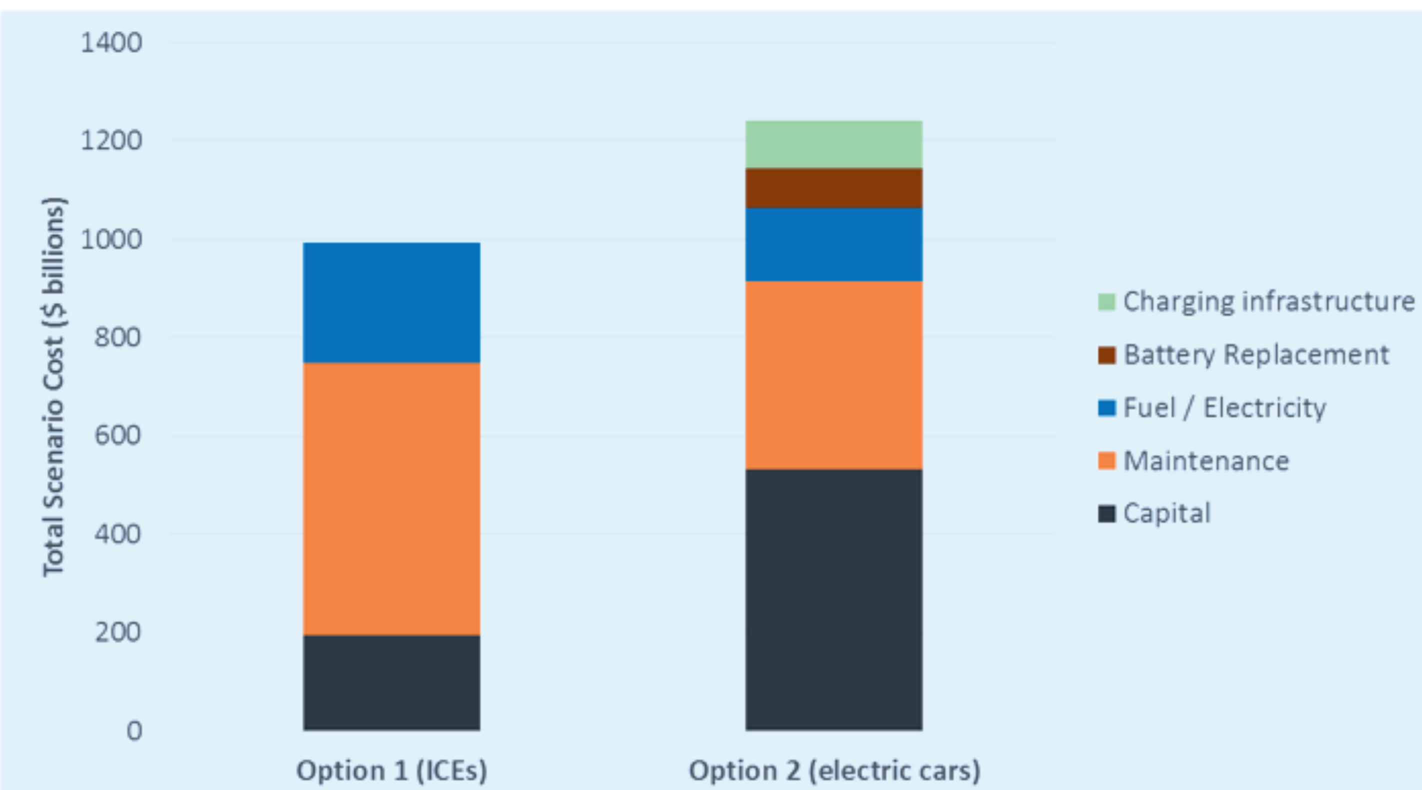


Figure 3 - Summary of High Cost Scenario costs (Net Present Value of total cost between 2015 and 2035).

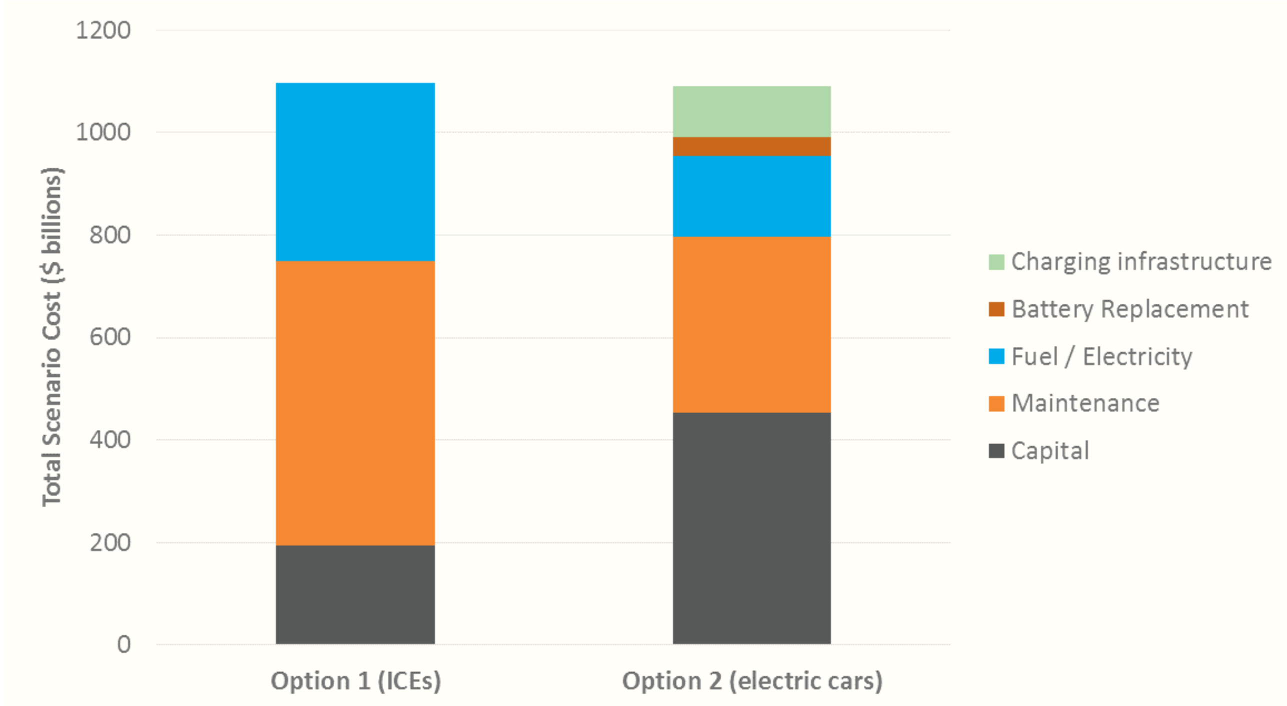


Figure 4 - Summary of Low Cost Scenario costs (Net Present Value of total cost between 2015 and 2035).

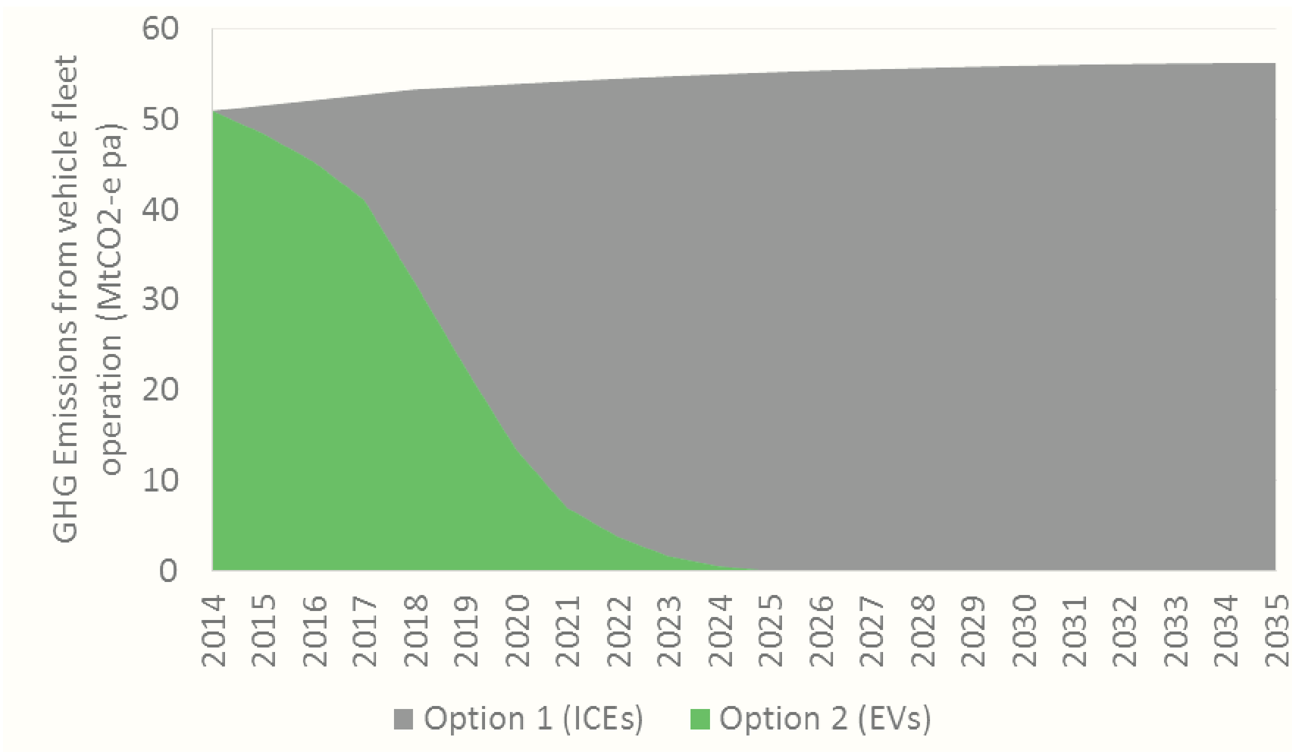


Figure 5 – Greenhouse gas (GHG) emissions related to operation of the car fleet.

that a shift to 100 per cent electric buses would cost almost 12 per cent less than continuing to operate ICE buses. This suggests that a shift to electric buses could, if conditions are favourable, make public transport cheaper.

Introduction

3 Introduction

With electric vehicle costs continuing to fall, a major tipping point is likely to occur [7]. Like the photovoltaics (PV) revolution that began in 2009, which saw PV costs plummet and installation rates soar [8], this transition could happen quickly, and could signal the beginning of a permanent shift away from oil as our primary transport fuel. The battery revolution is likely to see battery costs drop by between 20 and 60 per cent by 2020 [http://arena.gov.au/files/2015/07/AECOM-Energy-Storage-Study.pdf]. Both the battery and EV revolutions are closely linked - as battery prices fall, so too does the price of EVs.

Electric vehicles are a disruptive technology. This means it is a technology that will disrupt the existing market, displacing the existing technology. With Australia being long dependent upon international oil markets with a relatively small number of oil suppliers, the electric vehicle may finally allow Australia to use sustainable, domestically produced energy for our transport needs. The electric vehicle will allow us to harness our abundant renewable energy resources for this most critical of sectors: personal transport.

This report considers the potential for rapid uptake of EVs in Australia. Just as solar PV panels were a rare sight 20 years ago but are now seen in every suburb across Australia, electric vehicles will follow the same trend and increasingly be a regular occurrence on our roads. The report quantifies the costs of replacing all cars in Australia with EVs within 10 years. The most common EV worldwide - the Nissan Leaf - costs $39,000 in Australia, making it competitive with many other new cars on the market, particularly when the lower maintenance and lower fuel (electricity versus petrol) costs are taken into account. The report suggests that the shift to EVs may, under favourable conditions, cost the same as continuing to use traditional internal combustion engine (ICE) cars.

Figure 6 – Nissan Leaf EVs are a common sight in Colombo, Sri Lanka (Source: Stephen Bygrave)

3.1 Greenhouse emissions from cars in Australia

In 2013, almost 17 per cent of Australia's domestic greenhouse emissions were generated from the transport sector, as illustrated in Table 1. Cars are responsible for more than eight per cent of Australia's greenhouse emissions. Given that 75 per cent of passenger car kilometres travelled are in urban areas [9], this indicates that more than 6 per cent of Australia's total emissions are attributable to urban car travel. Urban cars are the largest single contributor to Australia's transport emissions, as illustrated in Figure 7.

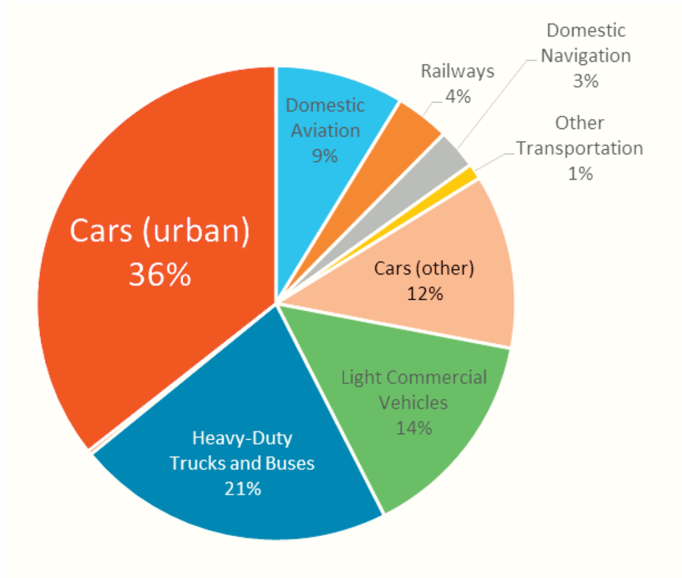


Figure 7 – Percentage contributions to Australia's transport sector emissions (2013). Source: [4]

Furthermore, transport emissions are one of the highest sources of emissions growth in Australia [10]. Emissions from the transport sector were 51 per cent higher in 2013 than in 1990, and on average have increased by 2.2 per cent annually [10]. Forecasts indicate emissions from the Australian car fleet will reach almost 58 million tCO2-e by 2020 [11]. Australia requires new

	GHG emissions (kilotons CO_2-e)	Percentage of Australia's total emissions
☐ Total Australian Emissions	549,446	100%
☐ Transport Total	92,682	16.87%
☐ Domestic Aviation	8,058	1.47%
☐ Road Transportation	77,716	14.14%
☐ Cars	44,042	8.02%
☐ Light Commercial Vehicles	13,440	2.45%
☐ Heavy-Duty Trucks and Buses	19,966	3.63%
☐ Motorcycles	268	0.05%
☐ Railways	3,389	0.62%
☐ Domestic Navigation	2,533	0.46%
☐ Other Transportation	986	0.18%
☐ Pipeline Transport	941	0.17%
☐ Other	45	0.01%

Table 1 – Total Australian emissions by sector in 2013, excluding fugitive emissions. Source: [4]

and innovative personal transport solutions to reduce our nation's greenhouse emissions and avoid dangerous climate change.

Greenhouse emissions from cars in Australia are significant, and this report suggests that a transition to EVs would be an achievable, realistic, and affordable possibility for eliminating them completely.

3.2 Objective of this report

This report aims to analyse the potential for zero carbon car travel in Australia by exploring whether:

1. Zero carbon personal car travel is technically possible and affordable, and can be achieved in the next ten years (by 2025); and

2. Zero carbon personal car travel compares favourably to present transport systems, when considered in terms of their cost, convenience, attractiveness and co-benefits.

3.3 Scope of this report

The scope of this analysis is defined as follows:

- *100 per cent electric* - The analysis only considers cars that operate on 100 per cent (renewable) electricity. Hybrids are not included for the purposes of this report, though they will play an important transition role in the shift to EVs. Biofuel or hydrogen fuelled cars are also not included. If these technologies become widely commercially available, costs could be lower than those presented in this analysis.

- *Cars* - This analysis is focused on cars[5]. Trucks, trains, trams, light rail, light commercial vehicles, bicycles, scooters, motorbikes and other personal mobility devices are not included. Urban buses are addressed in a separate model, outlined in Section 6. Public transport will be addressed more fully in a later report under the Zero Carbon Australia Plan.

- *Urban travel* - The analysis only considers urban travel (travel within Australian cities)[6]. Inter-city travel is not included. BZE's High Speed Rail report addresses some aspects of zero -carbon inter-city travel, and other aspects will be addressed in upcoming Zero Carbon Australia transport reports.

- *Personal travel* - The analysis only considers personal travel (the transport of people). Freight is not included, and will be addressed in an upcoming Zero Carbon Australia transport report.

3.4 Structure of this report

This report is structured as follows:

– Section 4 summarises current electric vehicle technology.

– Section 5 quantifies the costs of a shift to 100 per cent electric cars by 2025.

– Section 6 quantifies the costs of a shift to 100 per cent electric buses by 2025.

– Section 7 provides examples of some possible policy responses to these findings.

5 As highlighted earlier, an electric vehicle for the purposes of this report is a passenger car powered by electricity. The definition for a passenger car used by the Australian Bureau of Statistics (ABS) in their 9309.0 - Motor Vehicle Census [41] is applied: A passenger car is considered to be any motor car constructed primarily for the carriage of persons and containing up to nine seats (including the driver's seat). This category includes cars, station wagons, four-wheel drive passenger cars and forward-control passenger cars. Campervans are excluded.

6 Urban personal transport is defined as travel taken by people within Australian urban areas, as defined by the Australian Bureau of Statistics [72, 73]. The modelling included in this report quantifies costs for a transition of the whole Australian car fleet to electric, utilising nation-wide data. However, for non-urban travel (constituting around 25% of car travel in Australia [9]), further charging infrastructure beyond that modelled in this report is likely to be required.

– Section 8 concludes with a brief summary.

The detailed assumptions and modelling methodology applied are outlined in Appendix A (for the car fleet) and Appendix B (for the bus fleet).

Electric Vehicle Technology

4 Electric Vehicle Technology

Simply put, electric vehicles are powered by electricity, rather than fossil fuels. They have an electric motor instead of an internal combustion engine, they store their energy in a battery rather than in a fuel tank, and they are "refuelled" via a plug and cable, rather than via a petrol pump [6]. This section examines EV technology - given the rapid changes in EV technology it is not meant to be comprehensive but provides a brief overview of EV benefits, performance, current models as well as charging infrastructure requirements.

4.1 Benefits of electric vehicles

Why electric vehicles? This section outlines some of the potential benefits.

4.1.1 Zero greenhouse emissions

EVs can be powered by 100 per cent renewable electricity, and do not emit any greenhouse gases from the tailpipe. This modelling indicates that the shift to EVs operating on 100 per cent renewable electricity for car travel in Australia would eliminate approximately 55 Mt of CO2-e per annum. In Australia, car travel contributes eight per cent of national greenhouse gas emissions [4], with urban car travel contributing around six per cent. This means that a shift to EVs will make an important contribution to reducing Australia's greenhouse emissions, reducing at least 6 per cent of national emissions, and up to 8 per cent if regional car use is included.

4.1.2 Air quality improvements

Zero tailpipe emissions also means improved urban air quality, and will result in fewer fatalities relating to breathing toxic air. These benefits could be significant, given that motor vehicles are the main source of urban air pollution [6]. Tailpipe emissions from ICEs include carbon monoxide (CO), non-methane volatile organic compounds (NMVOC), nitrous oxides (NOx) and particulate matter (PM). These emissions contribute to urban air pollution and accumulate in soil and water, negatively impacting on human health [12] and degrading the quality of the natural environment [13]. EVs do generate some localised emissions from brake and tyre wear, but with an absence of tailpipe emissions provide a significant improvement over ICEs in terms of air quality. Improvements in urban air quality are likely to have significant flow on health and environmental benefits. A report from the OECD found that emissions from the use of ICEs is likely to cause approximately 500 - 1,000 deaths in Australia per year [12]. This is broadly equivalent to the annual road toll of 1,200 road fatalities per annum [14].

4.1.3 Reduced noise pollution

The electric drivetrain in an electric car is near silent in operation, which means that traffic noise can be reduced by a transition to electric cars. Road traffic noise has been identified as the most common noise source in Victoria [6]. A large body of research demonstrates the negative impacts of noise and vibration on health [15]. Transitioning our passenger vehicles to 100% EVs would transform our cities, making them more pleasant spaces to be.

4.1.4 Urban amenity

Traffic pollution and noise reduces the value of urban amenity, especially in major transport corridors where it can result in lower property values [15]. By reducing noise and vibration from car traffic, the adoption of electric cars could contribute to increased urban amenity and enable more intensification around busy transport corridors, especially when complemented by investment in public transport and other public facilities.

4.1.5 Operating cost savings

Electric cars cost significantly less to operate than ICE cars. Electric drivetrains have fewer moving parts and therefore lower maintenance costs [6]. Electricity is also less expensive per kilometre travelled than liquid fossil fuels, including factoring in the cost of 100 per cent renewable electricity. These operating cost savings help to offset the higher capital cost of electric cars.

4.1.6 Improving the electricity grid

One of the great opportunities of electric cars is their potential to help improve the efficiency of the electricity grid.

Vehicle-to-grid technology enables EVs to supply, as well as consume, electricity. This allows EV owners to purchase electricity cheaply when demand is low and sell it at a higher rate when demand rises. Not only would this enable EV owners to sell energy profitably, it would have major benefits for the grid as a whole.

Once large numbers of EVs are supplying electricity they will significantly reduce electricity generation requirements during periods of peak demand. This is a particularly valuable service for stabilising an electricity system powered by intermittent renewable energy sources. It will lead to better use of transmission and distribution networks and lower tariffs. Vehicle-to-grid technology is already in development and a trial market will be launched in Europe in Autumn 2016.

4.1.7 Energy security

EVs offer the potential to reduce reliance upon imported oil, minimising exposure to volatile foreign oil prices. Instead of fossil fuels, cars will be powered by domestically-produced, 100 per cent renewable energy. Research suggests that the volatility in the price of liquid fuels is likely to persist or increase in the future [16], indicating that the value in mitigating this risk could increase over time.

4.2 EV performance

4.2.1 Driving Experience

Participants in a Victorian Electric Vehicle Trial reported positive attitudes towards EV performance [6]. They were found to relatively seamlessly adopt the trial vehicles into their normal travel patterns, and were found to use the EV as their first-choice for vehicle travel [6]. This result is a strong endorsement for the potential for EVs to replace ICEs [6].

This finding arises from the inherent characteristics of electric motors, which are very responsive and generate maximum torque from rest (in contrast to ICEs, which generate maximum torque near the middle of their operating range) [6]. Torque is important because it dictates a car's rate of acceleration. Even mid-range electric cars have high rates of acceleration; for example, the Nissan Leaf can accelerate from 0 to 60km/hr in 4.2 seconds, and from 0 to 100km/hr in 9.7 seconds [17]. The Tesla Model S has very high acceleration compared with all classes of ICEs, being capable of accelerating from 0-100km/h in 4.2 seconds, powered by a 310kW electric motor [18]. This can be compared to a similar ICE, such as an Aston Martin Rapide, whose 350kW ICE drives the car from 0-100km/hr in approximately 5 seconds. With a low centre of gravity and distributed weight of the batteries, EVs also offer better handling than ICEs.

4.2.2 EV Models

The number of EV models in the mass market is changing rapidly, with new makes and models coming on to the market all the time. Table 2 below outlines the current electric car models available (new or second hand) in Australia in 2016 but this situation is expected to change and evolve quickly. This is only a small proportion of the electric car models that are currently offered internationally. As illustrated, car range varies from around 100km to 500km between charges. Some models are available with varying battery size (and therefore varying range), as selected at the time of purchase. Newer models are cheaper and offer increased range, both of these factors will increase the rate of uptake in Australia.

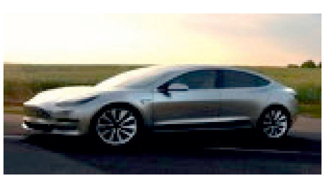
So is the range of electric cars sufficient to offer a viable substitute for ICEs?

The Victorian Integrated Survey of Travel and Activity includes data on 72,000 car trips, taken over a one-year period [5]. This data shows that the average daily driving distance for the Melbourne metropolitan area is 35 kilometres [5], which is well within the range of typical electric cars.

As illustrated in Figure 8, almost half of trips taken in that survey were less than 5km, and more than 90 per cent of trips were less than 30km. More than 99 per cent of the 72,000 trips

Table 2 – Mass-market electric cars in Australia (2015)

Model, since	Cost RRP (k$)	Range (km)	Notes
Nissan Leaf: **Since mid 2012** 	**40**	**117-175**	Top selling electric car in Australia and globally. 5-door hatch, front-wheel drive. 24kWh (21.3 usable) battery, 80kW motor,3.3kW charging, or 44kW fast charge. Curb weight: 1521kg
Mitsubishi i-Miev: **Since late 2010** 	**50**	**100-160**	First mass-market electric car in Australia. 5-door hatch, rear-wheel drive. Current availability is limited to special orders or second-hand. 16kWh battery. 3.3kW charging, 47kW motor. Curb weight 1080kg.

Model, since	Cost RRP (k$)	Range (km)	Notes
BMW i3: Since late 2014 	**from 70**	**130 (electric) 250 (total)**	Optional petrol generator gives extra 120km range. 5 Door hatch, rear-wheel drive. 130kW electric motor, 25kW 0.65L, petrol generator, 7.2L fuel tank Curb weight: 1195kg (1315kg with range extender).
Tesla Model S: Since late 2014 	**100-160**	**370-500**	First long-range pure electric car in Australia. 4-door sedan, rear-wheel drive and all-wheel drive options. 245kW – 515kW motor power depending on purchased configuration. Battery packs: 70kWh or 85kWh. Curb weight: 2108kg. 11kW per charger. Optional 2nd charger. 120kW fast charge.
Tesla Model 3: Late 2017 	**50-60**	**346**	Available to order now. Estimated time of arrival in Australia late 2017. 4-door sedan, rear-wheel drive. Motor power: TBA Battery packs: 44-66kWh Curb weight: TBA

taken in the survey were less than 120km, which is the range of a relatively modest electric car. A negligible number of the 72,000 trips recorded were longer than 400km.

From these data two facts emerge: 1) Australians make a lot of short car trips and 2) long car trips are relatively rare. This suggests that most EVs available have sufficient range to cover the majority of trips taken by typical urban users. Users that make several "trips" within a day will find that a 120km range allows for up to four trips of up to 30km (and 90 per cent of trips were less than 30km). Therefore, this data suggests that household charging alone is sufficient for the majority of drivers [6].

The Victorian Government Electric Vehicle Trial echoed this conclusion, finding that the average distance travelled between charge events was 36.9 kilometres, with a standard deviation of 8.8 kilometres[7] [6]. This trial found that at around six weeks into their EV experience, the majority of users were "only occasionally" concerned about vehicle range, or "hardly at all" [6].

The distribution of average daily driving distances in the Victorian Integrated Survey of Travel and Activity does reveal that there is a significant minority who travel further (much further in some cases) [6, 5]. To cater for these users, comprehensive public charging facilities have been included in the analysis in this report[8]. These would allow this minority of users to conveniently recharge as required throughout the day.

These results indicate that home charging alone will be sufficient for the majority of urban electric car users. For the minority of users that drive significantly longer distances, comprehensive public charging infrastructure has been included in the modelled scenarios, to ensure that all users will be adequately serviced.

4.3 Charging infrastructure

There are a range of options for charging electric cars, as described in the following sections.

4.3.1 Home charging

Most electric cars are likely to be charged at

7 Based upon "highly reliable data" obtained from 44 household vehicle allocations of three months.

8 Note that the assumed level of charging infrastructure included in the scenarios, despite being comprehensive, is found to cost only a small fraction of the total scenario cost.

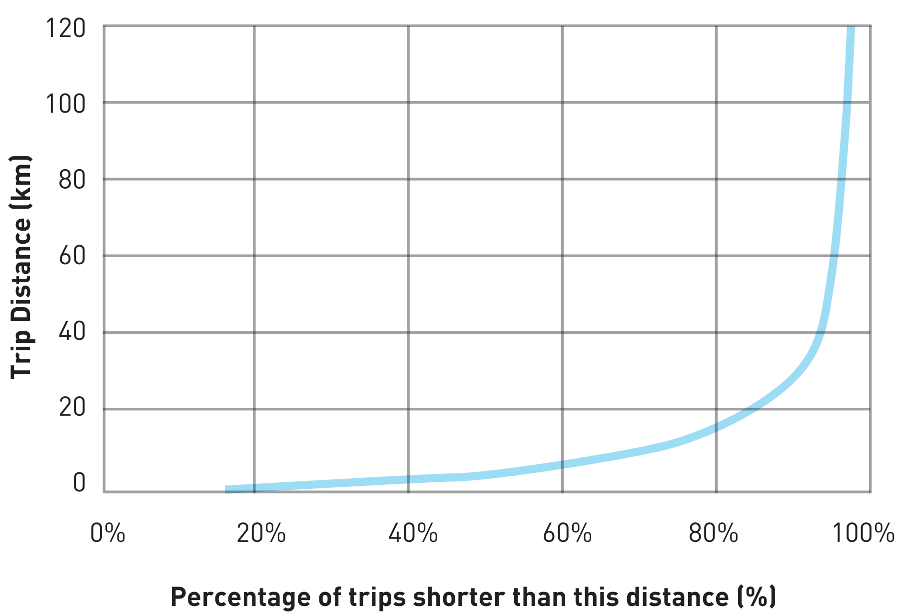


Figure 8. Trip data from the Victorian Integrated Survey of Travel and Activity (72,000 car trips over a one year period, 2009-10) [5]

home when they are parked overnight [19]. As discussed above, a single overnight charge is likely to be sufficient for the vast majority of users [6].

The analysis assumes that most EV purchasers will install a 'Level 2' charger at home. A Level 2 charger operates at around 30 Amps and can charge much more rapidly than a standard electrical socket, delivering around 100 km of charge in 3 hours, and a full re-charge of most recent model electric cars in around 4 hours. Level 2 chargers also generally offer additional safety, communication and control features. Installation of a Level 2 charger can be performed by a suitably certified electrician, installing dedicated wiring in the nominated garage.

EVs can usually also be charged via any standard ten or fifteen Amp outlet, if necessary, using a "convenience cord" provided with the vehicle. A typical electric car, (such as the Nissan Leaf) would require about 12 hours for a full charge from empty using this type of charging (note that with typical usage, a car will rarely be close to empty). This requires no special equipment except the cable provided, with the standard 10 Amp Australian power plug. Most users wouldn't be expected to use this option as standard, but it does provide an additional top-up alternative.

4.3.2 Public charging

There are two main options available for public charging of EVs at present. The first is Level 2 public charging facilities, which are similar to those that would be installed in most users' homes. These could be installed at any location where users typically park during the day, such as the workplace, shopping centres, public carparks, and on roadsides (via "bollards"). These would offer users the opportunity to "top-up" their charge level while they shop or go about their usual activities throughout the day, and would offer similar charge rates to home Level 2 chargers (around 100 km of charge in 3 hours, and a full re-charge of most recent model electric cars in around 4 hours). The use of these facilities may be offered free-of-charge to customers, or they may include payment facilities, depending upon the preference of the business, government or council installing and maintaining them.

The second alternative for public charging is "rapid" charging, or "fast" charging facilities. These offer the potential to re-charge up to 80 per cent of an electric car battery in 30 minutes. Tesla's 'Supercharger' are yet another example, with a network of rapid charging stations proposed along the east coast of Australia, as illustrated in Figure 11. These offer the potential to enable continuous travel, and allow users that drive almost constantly throughout the day to access the benefits of an EV. The spacing of Tesla's charging stations is intended to allow users travelling between cities to top-up their charge at about the same frequency that a typical driver would want to pause their drive for a short rest, in line with road safety guidelines.

Other models for charging have been proposed, such as swappable batteries. Electric cars could be designed such that upon driving into a swap station, the battery could be exchanged for a fully charged battery in two or three minutes (or less). The vehicle drives over a hatch at a charging station, and a robot removes and replaces the battery. This operation can be completely automated, such that the driver need not leave the vehicle.

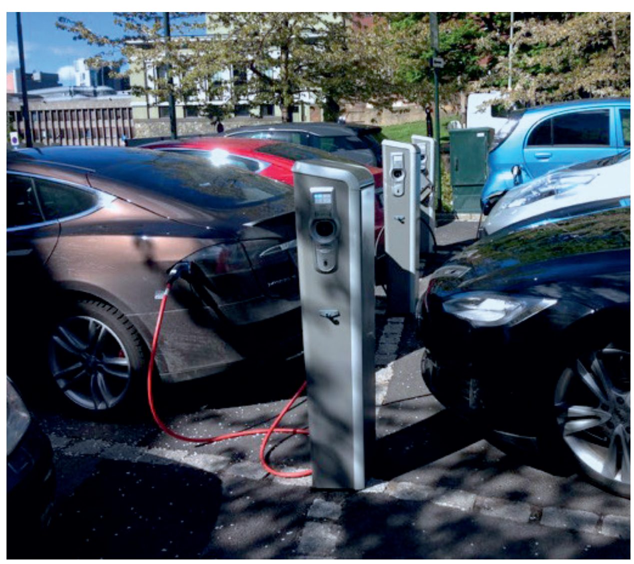


Figure 9 - Level 2 Public charging facilities in Oslo, Norway (Source: Stephen Bygrave)

Inductive charging may be another option; in this model charging occurs wirelessly. A charging pad is fixed to the ground under where the electric car parks, and the electric car is fitted with receiving equipment under the chassis. No cables or plugs are required. One manufacturer in the USA (pluglesspower.com) is offering inductive charging for the Nissan Leaf and Chevy Volt. A display screen on the wall in front of where the vehicle parks provides directional arrows to the driver when parking, to align the pad and receiver. They rate the system at 3.3kW, sufficient to fully charge a Leaf from empty in approximately 8 hours. With an air gap of around 10cm between pad and receiver, energy transfer rates of up to 90% can be achieved [20].

The modelling in this report assumes that a level 2 charger is installed in the home of each EV owner, and that an additional level 2 public charger is also installed in an urban area for each EV purchased. A network of rapid charging stations is also assumed. Swappable batteries and inductive charging have not been included due to the relative immaturity of these technologies, but if they evolve rapidly they could serve to bring costs down further, and provide even greater levels of convenience.

Figure 10 - Tesla's highway public charging facilities (Source: Stephen Bygrave)

4.4 Powered by 100 per cent renewable energy

The modelling in this report assumes a shift of the electric power system to 100 per cent renewable energy in ten years. Such a shift has been found to be feasible and affordable in a previous Beyond Zero Emissions report [1], with the result now corroborated by research at the University of New South Wales [21, 22, 23], as well as a detailed study by the Australian Energy Market Operator [24].

Even before achieving a 100 per cent renewable power system, 100 per cent renewable energy can be easily purchased via "Greenpower" - usually for a small additional cost. This is available to any consumer in Australia (residential, commercial and industrial). Greenpower uses a rigorous certification system to ensure sufficient electricity is generated from renewable sources to meet their consumers' demand. Thus, although the source of the electrons used by any particular customer are indistinguishable, purchasing Greenpower is equivalent to the direct use of renewable energy.

4.4.1 Using solar photovoltaics

The significant cost reductions in photovoltaics (PV) technology in recent years creates additional opportunities for charging electric cars directly from rooftop solar panels. If managed carefully, co-locating generation (PV) with electric cars can limit negative cost impacts of either technology on the distribution grid. Many charging stations are incorporating photovoltaics, as a way of enhancing the sustainable credentials of the technology, and reducing costs by minimising impacts on local grids.

From an individual's perspective, there may be advantages in expanding home PV installations upon purchase of an electric car. Most Australian states have now reduced or removed the feed-in-tariffs paid for PV electricity fed back into the grid, meaning that home owners may now only receive 6-8c/kWh for PV power. However, typical tariffs for purchasing electricity from the grid are in the range 25-30c/kWh, since they include significant costs associated with the installation and maintenance of distribution networks. This means that there is significant benefit in using the power generated by PV on-site, to minimise purchases from the grid. If an electric car is plugged in and is charging at home during the day, this can create additional electrical load to absorb the generation from the PV system, limiting the generation fed back into the grid during those times. This provides cheap electricity for charging the electric car, protected from future electricity price increases. With the further advent of affordable home battery storage, users with a combination of home storage, PV and electric cars may find additional opportunities to optimise their home energy generation and usage.

Figure 11 - Tesla's proposed network of rapid charging stations, to enable inter-city travel in the Tesla Model S (Image courtesy of Tesla Motors)

Modelling a Transition to 100 Per Cent Electric Cars

5 Modelling a transition to 100 per cent electric cars

5.1 Assumptions

A model was developed to quantify the costs and benefits of transitioning to a 100 per cent electric car fleet by 2025. The model calculates costs for two options:

1. Option 1 - Business as Usual (BAU): This option assumes that the size and composition of the car fleet changes in line with historical trends, and remains dominated by ICE cars.

2. Option 2 - Technological Change: This option assumes that the size and composition of the car fleet changes in line with historical trends, except ICE cars are progressively phased out from 2015, such that the urban car fleet consists solely of electric cars by 2025. This transition is depicted in Figure 12.

The key parameters and definitions applied in this modelling are summarised in Table 3. The detailed assumptions and modelling methodology are outlined in Appendix A.

The costs associated with each Option were quantified under two Scenarios: A “High Cost” Scenario and a “Low Cost” Scenario. These Scenarios differ in a range of assumptions which have an important influence over total costs, and are uncertain. The key assumptions in each scenario are summarised in Table 4.

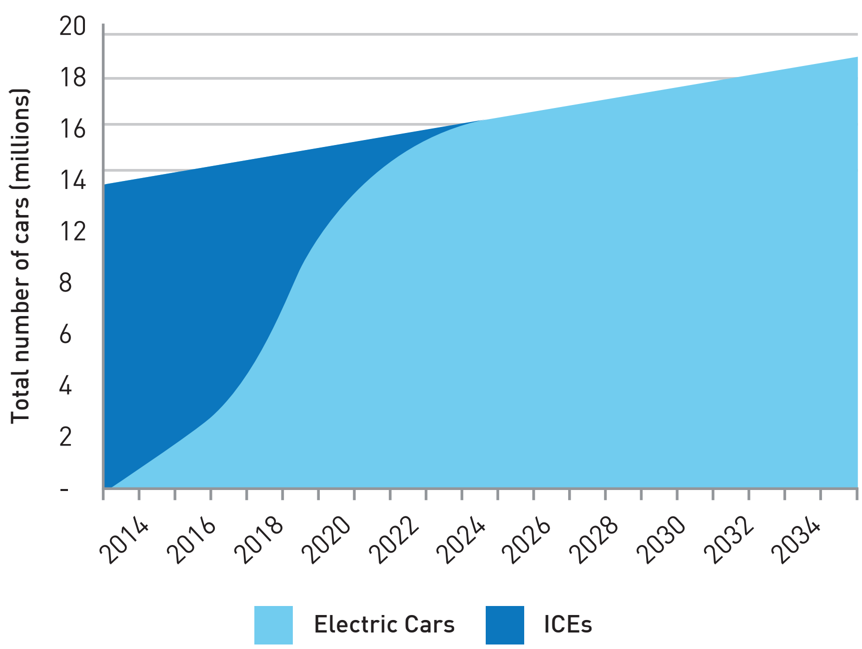


Figure 12 – The transition of Australia’s car fleet from ICE cars to electric cars.

Table 3 - Key Parameters and Definitions

Parameter	Definition
Time frames	☐ In Option 2, Australia's car fleet is entirely converted to electric cars by 2025. ☐ Costs were quantified in each year of a 20 year evaluation period (2015-2035). This captures long term financial effects of the transition to electric cars.
Electricity source	The electricity supply in Australia is assumed to be converted to 100 per cent renewable by 2025. The cost of electricity is calculated for a 100 per cent renewable power system, as quantified in the Beyond Zero Emissions Stationary Energy Plan [1].
Discount rate	A conservative discount rate of 8.0 per cent per annum was applied. This "discounts" the value of future expenditure compared with present expenditure. This rate is relatively high given the current economic climate (a higher rate will tend to undervalue the longer term benefits of a shift to electric cars), but is selected to ensure conservative assumptions.
Scope	This analysis explores personal travel within Australian cities and urban areas. Freight and inter-city travel are not included.
Technologies	This analysis focuses on the application of electric car technologies, including small, medium and large electric cars[1]. Electric buses are addressed separately in section 6.

Table 4 – Modelling Assumptions for each Scenario

	High Cost Scenario	Low Cost Scenario
Electric car capital costs	Reach parity with ICEs in 2035 (slow capital cost reduction)	Reach parity with ICEs in 2025 (fast capital cost reduction)
Battery replacement costs	Battery cost projections based upon the US Energy Information Administrations "Annual Energy Outlook" reference case	Battery costs reduce more rapidly, assuming significant breakthroughs in electric car battery technology in line with the program goals established by the USA Department of Energy
Maintenance costs	Electric car maintenance costs are assumed to be 75 per cent of those for ICEs	Electric car maintenance costs are assumed to be 20 per cent of those for ICEs
Petrol prices	Petrol prices follow a central price projection, from a model developed by the Bureau of Infrastructure, Transport and Regional Economics (BITRE)	Petrol prices follow a high price projection from the BITRE model

The High Cost Scenario is considered to be "conservative", in that it is likely to over-state the costs of the shift to 100 per cent electric cars.

The following assumptions were applied in both scenarios:

- *Size and composition of the car fleet* - projected based on a linear extrapolation of historical trends.

- *Kilometres travelled per vehicle* - projected based on a linear extrapolation of historical trends.

- *Electricity costs* - assumes 100 per cent renewable electricity, as in the Zero Carbon Australia Stationary Energy Plan [1].

- *Battery replacement* - electric car batteries are replaced after ten years of operation.

- *Household charging* - A Level 2 charger is installed in every house when an electric car is purchased.

- *Public Level 2 charging* - for every new electric car purchase a Level 2 public charging unit is assumed to be installed somewhere within an urban area in Australia.

- *Rapid charging* - Included at a rate of one station per five kilometre radius circle (or one station per 80 square kilometres) for all urban areas in Australia. Each station was assumed to have 10 rapid charge points.

All prices throughout this report are quoted in real 2014 dollars.

5.2 Methodology

The modelling methodology used to evaluate these Options is summarised in Figure 13. Population projections and historical analysis of car fleet composition trends were used to estimate the likely size and composition of the car fleet from 2015 to 2035. Costs for each option were then quantified, including the capital costs of ICEs (Option 1) and the capital costs of electric cars and associated charging infrastructure (Option 2), as well as the operation and maintenance costs of ICEs and electric cars, and the fuel costs for petrol (Option 1) and electricity (Option 2). The greenhouse emissions from each scenario were also quantified. Where robust projections of the required input data were available, these were used in the model. In other cases, historical data was projected forward assuming a linear continuation of trends. This approach is outlined in more detail with all assumptions discussed in Appendix A.

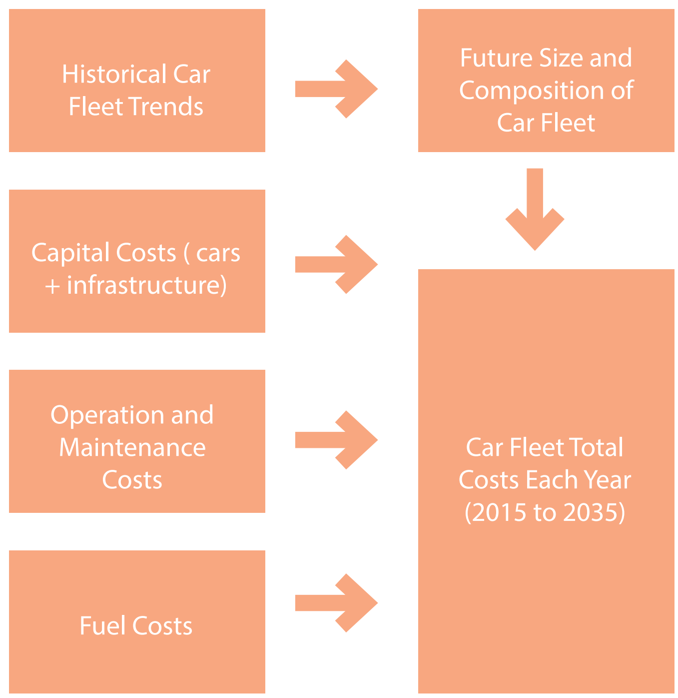


Figure 13 - Modelling methodology

5.3 Results

5.3.1 High Cost Scenario

The High Cost scenario applies conservative assumptions to the costs of electric cars, charging infrastructure and petrol prices. Costs are compared in Figure 14 for the two options: continuing to use ICEs (Option 1), or a transition to 100 per cent electric cars by 2025 (Option 2). Note that costs have been aggregated over the period 2015 to 2035 to ensure that the fuel cost savings from transitioning to electric cars are captured (with appropriate discounting) [9].

With these assumptions, total costs incurred in Option 1 (which assumes continuing use of ICEs) over the period 2015 to 2035 are calculated to be $993 billion. Costs are calculated to be 25 per cent higher in Option 2 with a shift to 100 per cent electric cars ($1,243 billion over the period 2015 to 2035). A zero carbon urban personal transport solution thus amounts to an increase in cost of around $20 per capita per week, with conservative assumptions.

Figure 15 illustrates the costs of the car fleet (excluding the costs of charging infrastructure) over time for Option 1. Figure 16 shows the same for Option 2. In Option 1, costs are incurred progressively over time as the car fleet size gradually increases. In contrast, Option 2 requires large capital investment in the first decade as the fleet rapidly transitions to electric cars. Costs are then significantly reduced in the second decade. Battery replacement costs are entirely incurred in the second decade, as batteries are replaced in electric cars that are more than ten years of age.

5.3.2 Low Cost Scenario

The Low Cost Scenario assumes:

- Capital costs for electric cars reduce more rapidly, reaching parity with ICEs in 2025 (rather than 2035), as discussed in section 9.3.1;
- Battery replacement costs for electric cars reduce more rapidly, assuming significant breakthroughs in electric car battery technology in line with the program goals established by the USA Department of Energy, as discussed in section 9.3.3;
- Maintenance costs for electric cars are 80 per cent lower than ICEs (rather than 25 per cent lower), as discussed in section 9.4.2; and
- Petrol prices follow a high price projection (rather than a central price projection), as discussed in section 9.5.2.

Figure 18 compares the total costs for each option in the Low Cost Scenario. Under these assumptions the total costs incurred in Option 1 (which assumes continuing use of ICEs) over the period 2015 to 2035 are found to be almost identical to the total costs in Option 2.

This indicates that if petrol prices are at the high end of projections, and electric car and battery technology costs decline at the more rapid rates being projected by some analyses, then a rapid to transition to 100 per cent electric cars operating on 100 per cent renewable electricity might cost no more than continuing use of ICEs. This would eliminate six per cent of Australia's greenhouse emissions (the proportion currently attributed to urban cars) at no additional cost [25].

Figure 19 illustrates the distribution of costs over time in the Low Cost Scenario, for the transition to electric cars. As for the High Cost Scenario, there is a significant initial expenditure in the capital cost of electric cars, and a subsequent expenditure on battery replacement after ten years of operation. Costs for operations and maintenance and capital are lower than in the High Cost Scenario depicted in Figure 16.

5.3.3 Cost Breakdown

In Option 1 the majority of cost is found to be in car maintenance, with capital costs and fuel costs also being significant.

Option 2 has significantly higher capital costs due to the replacement of the entire car fleet with electric cars in ten years. However, maintenance costs are significantly lower, and fuel costs are also reduced[10]. Cost components for each

9 This modelling assumes a transition to 100 percent electric cars by 2025 (in ten years). The total costs of this transition are calculated over a twenty year evaluation period (2015 to 2035), to ensure that all the capital costs and operating costs are properly captured over the long term, with an 8 percent discount rate.

10 Fuel costs in Option 2 (electric cars) increase slightly in the Low Cost Scenario due to the higher petrol price, which is applied to the operation of the diminishing proportion of ICE cars prior to 2025.

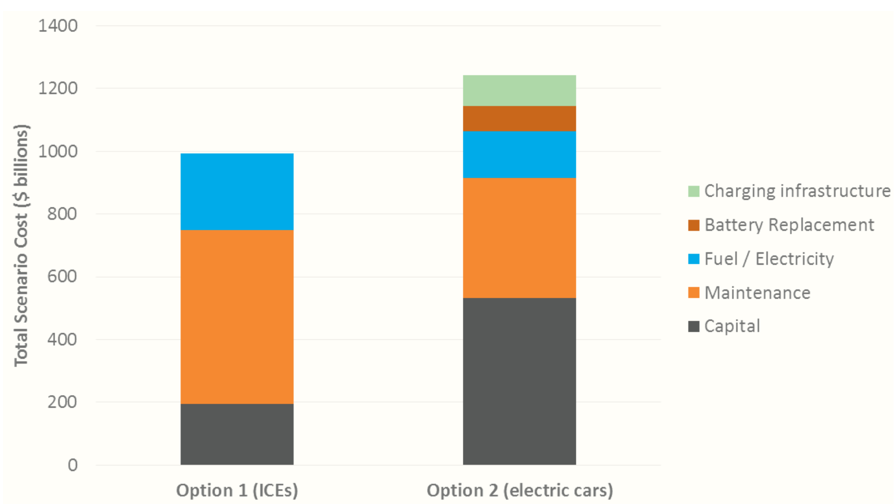


Figure 14 - Summary of costs (Net Present Value of total cost between 2015 and 2035) in the High Cost Scenario.

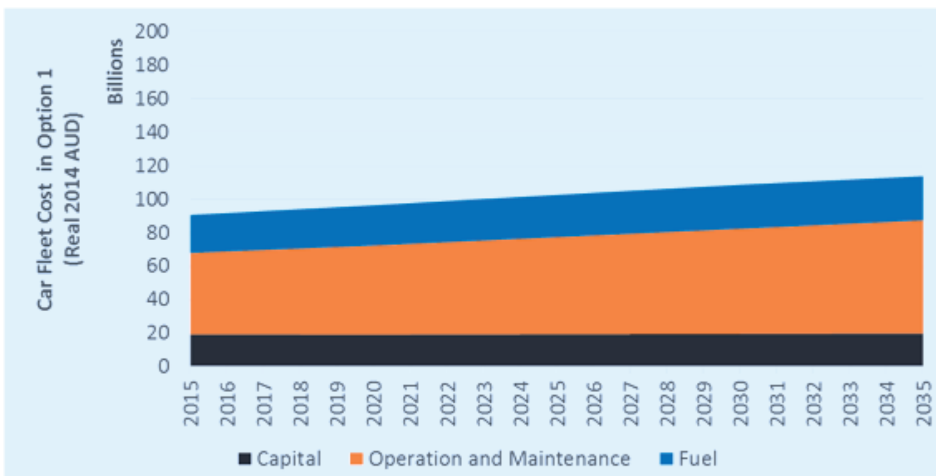


Figure 15 – Car fleet costs in Option 1 (ICEs) as incurred over time (High Cost Scenario)

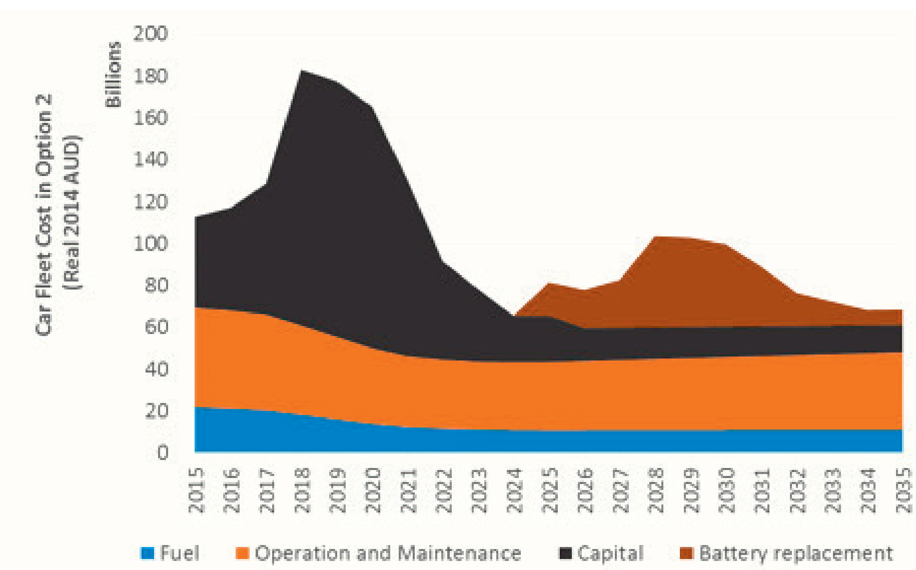


Figure 16 – Car fleet costs in Option 2 (electric cars) as incurred over time (High Cost Scenario)

Figure 17 – Solar EV charging - Willoughby Council Sydney

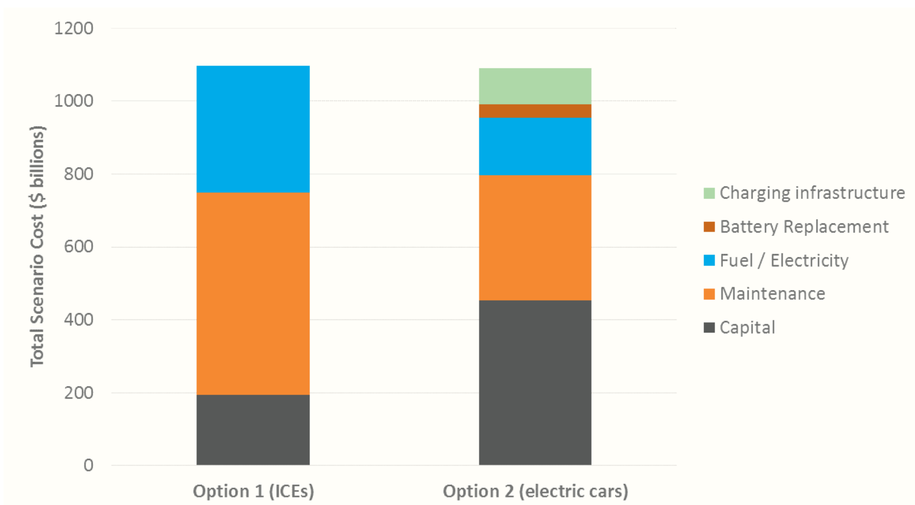


Figure 18- Summary of costs (Net Present Value of total cost between 2015 and 2035) in the Low Cost Scenario

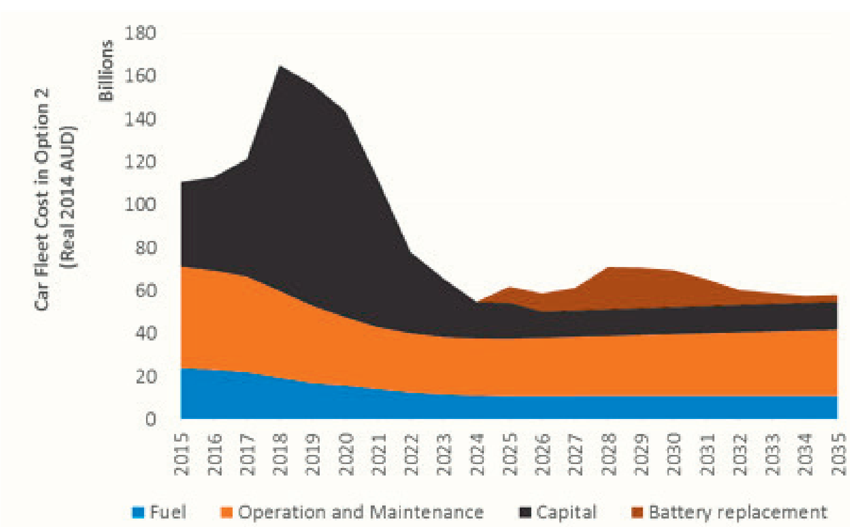


Figure 19– Car fleet costs in Option 2 (transition to electric cars) incurred over time in the Low Cost Scenario

scenario are compared in Table 5 (with the Low Cost Scenario in brackets).

If the transition to electric cars occurred more slowly than assumed in this report, then the costs associated with the transition would be lower than predicted in previous sections. This reduction in costs arises from the fact that the higher capital costs of electric cars is deferred, such that the technology is cheaper and capital costs are discounted more heavily.

5.3.4 Greenhouse gas emissions

Figure 20 compares the greenhouse gas (GHG) emissions from the operation of the car fleet in each option. In Option 2, emissions rapidly decrease to zero (based upon the assumption of operation on 100 per cent renewable electricity). In Option 1, greenhouse emissions continue to grow over time as the car fleet grows. Note that this analysis does not include any consideration of emissions related to the manufacture of cars; only tailpipe emissions are considered. Also note that even in the absence of a 100% renewable electricity system it would be possible to power the entire electric car fleet on 100% Greenpower, ensuring zero greenhouse emissions, as discussed in section 4.4.

5.3.5 Car charging infrastructure

The total cost of installing and operating car charging infrastructure was calculated to be $295 per annum, per capita over the study period (or $5.70 per week per capita). This is composed of expenditure for household level 2 chargers ($42 per annum, per capita); public level 2 chargers ($252 per annum, per capita); and rapid charging facilities ($0.68 cents per annum, per capita). These proportions are illustrated in Figure 21.

The majority of charging infrastructure costs is associated with public level 2 charge points. This modelling assumed one public level 2 charge point being installed per electric car in the fleet. Given that the majority of charging is anticipated to be performed at home, and that public charging points are able to be shared between cars, it may be possible for fewer public charge points to be installed, reducing charging infrastructure costs substantially.

Despite having a high unit cost, the total cost of rapid charge points is small by comparison to the other types of charging infrastructure. This reflects the fact that only a small number of rapid charge points are assumed to be required,

Cost elements		Option Cost ($ billions) Net Present Value of total cost 2015 to 2035		
		Option 1 (ICEs)	Option 2 (electric cars)	Difference
Car Fleet	Capital	194	532 (453)	338 (259)
	Maintenance	556	384 (344)	-172 (-212)
	Fuel	243 (347)	148 (158)	-95 (-189)
	Battery Replacement	0	79 (36)	79 (36)
	Charging infrastructure	0	100	100
Total		993 (1097)	1243 (1090)	250 (0)
Total per capita per week (dollars)		$81 ($89)	$101 ($89)	$20 ($0)

Table 5 – Net Present Value of total cost (2015 to 2035). Values in brackets indicate alternative costs for Low Cost Scenario

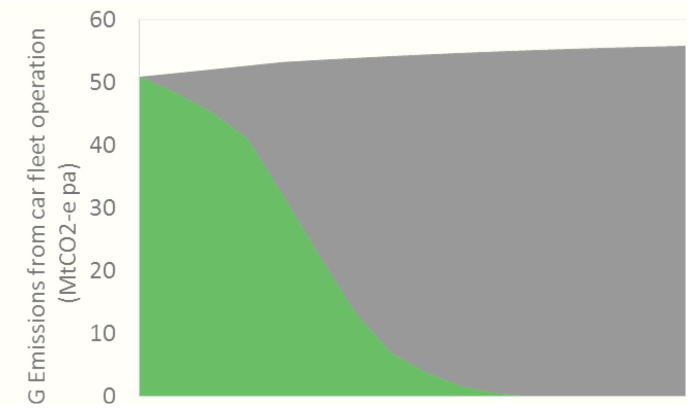


Figure 20 – GHG emissions related to operation of the car fleet

specifically one charging station with 10 rapid charge points per 5km radius region in urban areas (or equivalently, one charging station per 80 square kilometres). This led to 592 charging stations in urban areas around Australia, compared with over 8,000 petrol stations at present. This is considered sufficient because only a small proportion of charging is anticipated to occur at rapid charge stations.

As petrol stations become redundant the land they currently occupy would become vacant and therefore available for other purposes. Based on average land values the sale of this land would realise $270 million in economic benefit. This is sufficient to more than offset the cost of installing and operating the rapid charging stations in Option 2 ($231 million). In fact, given that many petrol stations are located on valuable urban land, $270 million is considered a very conservative estimate and their sale could create a much larger economic benefit.

5.3.6 Additional electrical load

Option 2 would require an increase in electrical generation of 43 TWh per annum by 2025, and 45 TWh by 2035. This would be an increase of 18 per cent from the present total Australian electricity generation of approximately 255 TWh per annum [26].

This is very similar to the quantity projected in the Zero Carbon Australia Stationary Energy Plan (50 TWh per annum for electrification of all transport, including freight and inter-state travel, which is not included in this analysis) [1]. This confirms internal consistency of this modelling process, and validates the use of the electricity price projections from that analysis.

Electrical loads from the charging of electric cars can be actively managed through mechanisms such as intelligent time-of-use tariffs (which would provide a price signal to guide consumers on the optimal times to charge their car) or direct load control (whereby consumers would have incentives to allow the system operator or a third party to directly control the charging of their car). The implementation of such mechanisms would mean the additional electrical load would

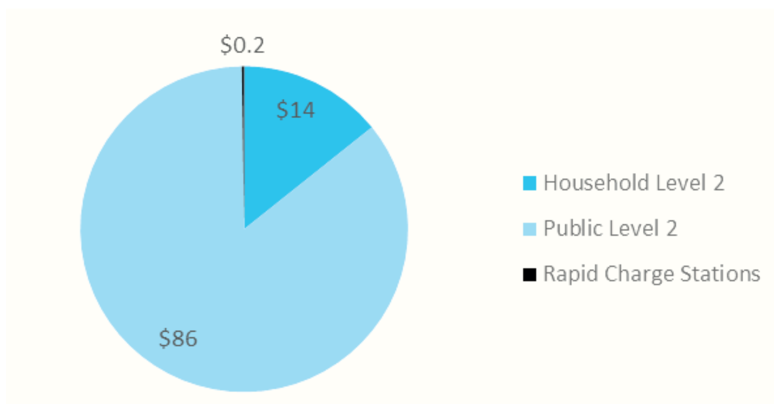


Figure 21 – Proportion of charging costs due to different types of charging infrastructure ($ billions NPV)

occur primarily during off-peak periods. This has been termed a "trough-filling" approach, and is illustrated in Figure 23. This figure shows the amount of additional electrical load from a shift to 100 per cent electric cars and electric buses for NSW and the ACT, superimposed on a week of typical electrical demand in those regions. A week in January 2014 is illustrated; the mid-summer period is when peak demands will typically occur, and the electricity system will therefore be under the largest amount of stress.

Figure 23 indicates that the additional electrical demand from electric cars and buses can be accommodated in the off-peak and shoulder periods, and therefore does not contribute to additional peak demand. This suggests that the existing electricity generation and transmission system should be sufficient to supply the required additional demand, with minimal augmentation. Similar results were found for other regions.

The increase in electrical demand, managed appropriately to occur in off-peak periods, could serve to increase network utilisation. This could reduce network tariffs (the c/kWh charge for use of the electricity network) [7].

Impacts on local distribution networks are more difficult to predict, since they can be very location-specific. However, ongoing development of distributed energy resources and the growing potential for distributed storage is likely to provide new opportunities to develop intelligent solutions to issues that may arise.

Figure 22- A highway public charging station in Norway, showing different charging points for different EVs

5.3.7 Car import and manufacture

Option 2 will require a significant increase in the number of cars entering the fleet over the next decade, as illustrated in Figure 24. Under business as usual, typical car sales in Australia (including used imports and new cars) are projected to total around one million per year. To meet the required take-up of electric cars, total car sales would need to rise to approximately 2.7 million per annum for the period 2018 to 2020. This increase could either be met by a rapid expansion of local manufacturing of electric cars, or an expansion of imports of electric cars.

The global market for electric cars is rapidly expanding. As of the end of 2014, there were more than 665,000 electric cars in operation in the world [27]. Electric car sales more than doubled from 45,000 in 2011 to 113,000 in 2012, then increased by 70 per cent to 2013, and a further 53 per cent to 2014 [27]. The International Energy Agency has projected an electric car stock of 24 million by 2020 [28]. Figure 25 illustrates the sales of electric cars that would be required in Australia, as a proportion of the global sales of electric cars projected by the IEA [28]. This analysis suggests that the supply of the electric cars required in Australia would constitute the majority of the global supply of electric cars in the early years of the analysis. In this case, it is likely that the global supply would expand more rapidly to meet this increased demand. In the later years of the analysis, Australia's demand for electric vehicles constitutes only a small proportion of the projected global supply of electric cars, suggesting that the import of the required number of electric cars would not pose a barrier.

Throughout the study timeframe, car imports to Australia are a minor portion of the total number of cars being manufactured globally (approximately 60 million per year) [29]. In 2015, Australia would require only 1 per cent of those cars, and a maximum of 5 per cent of those cars in 2019.

5.4 Scenarios for faster, more efficient transition to EVs

The central modelling for this report makes the simple assumption that the total number of cars will continue to rise slowly. However, several factors could lead to overall demand for cars falling in the coming decades. One important development is the rise of car sharing and e-hailing services like Uber. For example, it is estimated that every new shared vehicle replaces 10 privately owned cars. The trend towards such services is expected to accelerate once autonomous vehicles become available. (Several manufacturers plan to launch autonomous road vehicles in the next five years.)

Another possibility is that a more integrated approach to transport leads to fewer journeys made by car. Targeted programs can increase the use of public transport and other modes of transport such as cycling and walking. Programs of this type have led to lower car use in several European cities. In fact, the trends described above are already leading to declining car ownership in many developed countries, especially among young people in cities.

There is therefore the real possibility that the

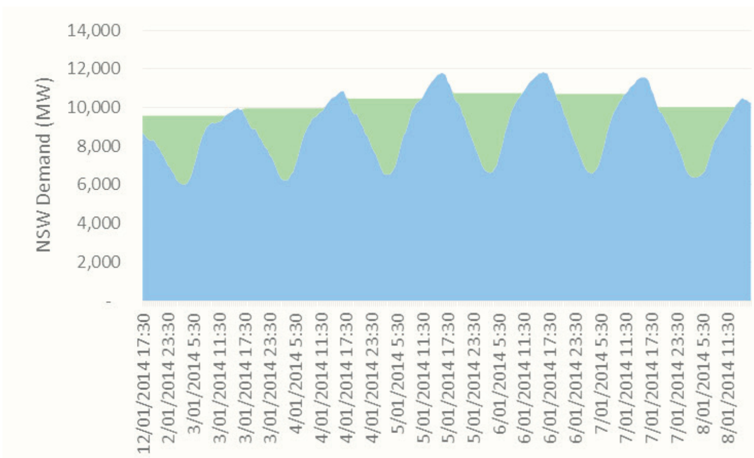


Figure 23- Illustration of increased electrical load in New South Wales due to electric cars and electric buses in 2035

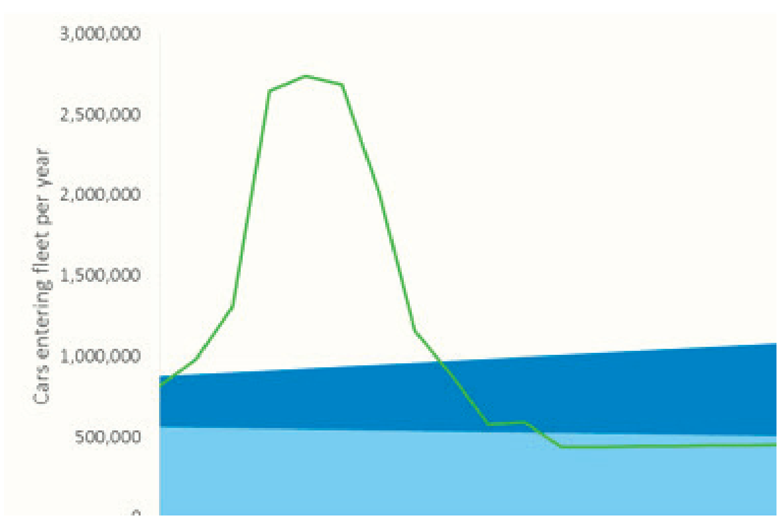


Figure 24 - Comparison of cars entering the fleet in Options 1 and 2 (green)

total vehicle fleet will be much smaller by 2025. An example of this scenario is shown in Figure 26. The figure indicates the growth trend in the overall vehicle fleet in Australia under a Business As Usual (BAU) scenario to 2030. It also shows the number of vehicles that would be made redundant through a shift to shared vehicles, public transport and other transit modes. This accelerated redundancy in the passenger leaves a much smaller active fleet that needs to be replaced by EVs, with the whole fleet becoming electric at a rapid pace. Assuming a fleet redundancy rate of 9-10 per cent per year from 2015 to 2025, shown by the yellow area, the ICE fleet quickly declines, and the active fleet quickly becomes entirely comprised of EVs. This scenario, which is extremely plausible, means the shift to 100 per cent EVs could occur even more quickly and cost effectively than modelled in this report.

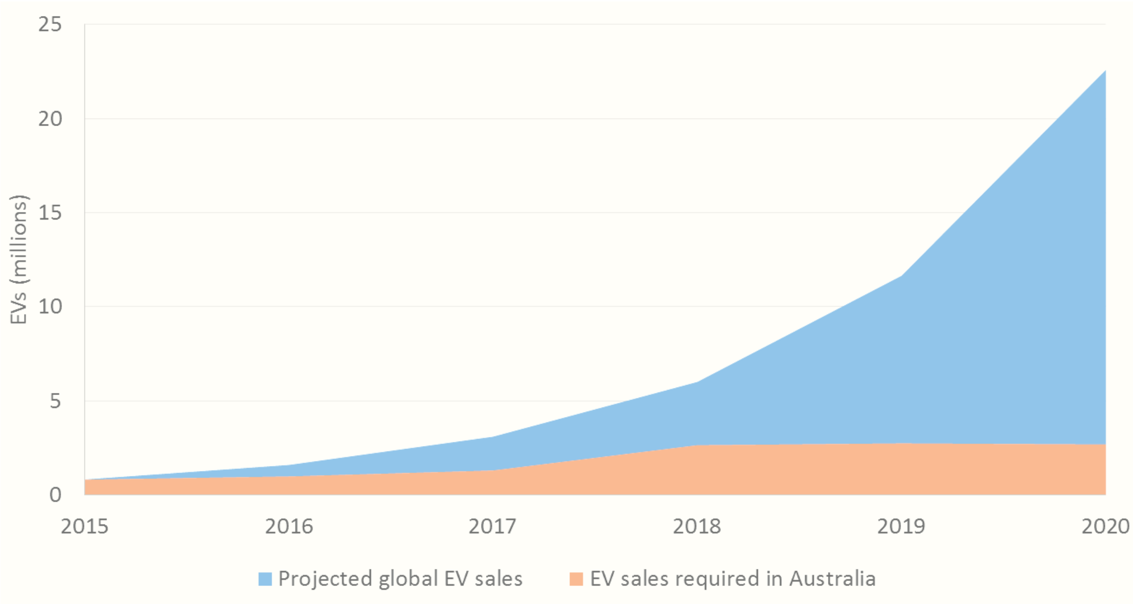


Figure 25 - Australian electric car sales required to achieve a rapid 100 per cent transition to electric cars, as a proportion of projected global electric car sales. Assumes compounding growth in sales, to achieve a stock of 24 million electric cars globally by 2020.

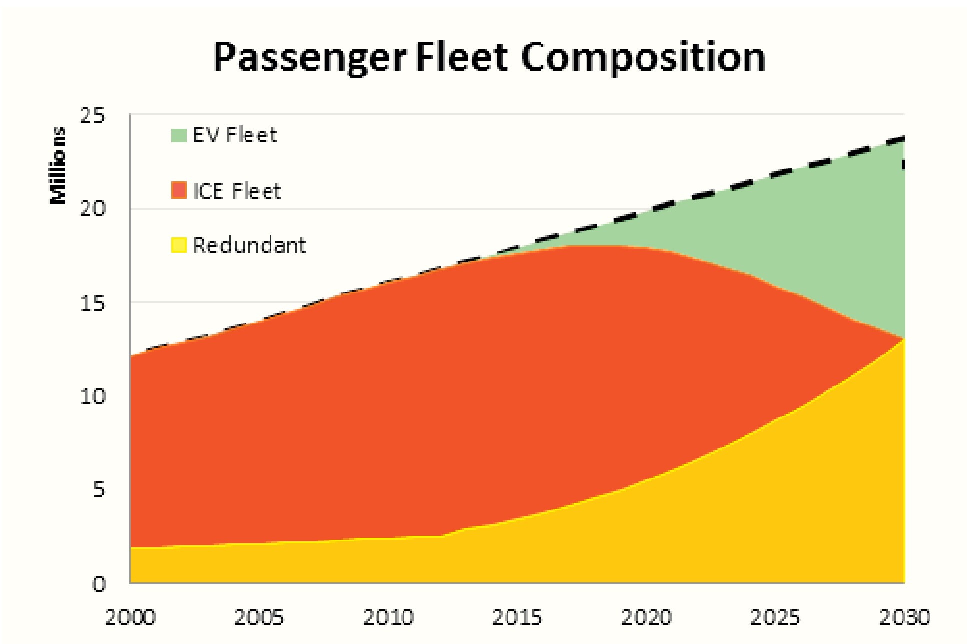


Figure 26 – More rapid and cost-effective transition to EVs, showing changes to passenger fleet composition from demand management and mode shifting

Electric Buses

6 Electric Buses

Public transport is likely to play an important role in a zero carbon urban transport system. Public transport has the ability to transport large numbers of people, over medium to long distances, in an energy efficient manner [30]. Public transport vehicles can also be operated more intensively, both in terms of kilometres and duration, than the average privately owned car. This suggests that public transport may be well suited to a transition to more capital intensive technologies, such as electric vehicles.

Buses are a ubiquitous feature of urban public transport systems and this role is likely to increase in the future. Once operating, electric buses tend to cost significantly less to maintain than ICE buses, for similar reasons discussed in relation to electric cars. However, as for private cars, electric buses have higher capital costs than their diesel equivalents. Electric buses have been trialled successfully in places such as Copenhagen, Genoa, and Quebec [31, 32, 33], and China has 36,500 electric buses in operation [27].

Figure 27 - BYD electric bus deployed in Copenhagen

Electric buses need to operate continuously throughout the day, and therefore need dedicated rapid charging infrastructure [34]. Some types of electric buses are able to drive relatively long distances on a fully-charged battery, usually 200-300 km. The fastest recharge-time is currently approximately 10 minutes [31, 35, 36], which can be accommodated between routes, if charging infrastructure is appropriately placed. Other types of charging infrastructure may make it possible for electric buses to charge in small top-ups during time stopped at bus stops [33]. Yet other innovations, such as induction charging for on-road top-ups and/or swappable batteries, may offer potential for this to be relatively seamlessly introduced into the typical bus route.

6.1 Modelling a transition to electric buses

A transition to electric buses was modelled using the same methodology as applied for the private electric car fleet, as outlined in Section 5.2. The assumptions used for modelling electric buses are outlined in detail in Appendix B.

Costs calculated for the bus fleet are illustrated in Figure 28 for the High Cost Scenario, and Figure 28 for the Low Cost Scenario. A transition to 100 per cent electric buses by 2025 was assumed, and with costs assessed over a twenty year evaluation period (2015 to 2035).

This modelling indicates that in the Low Cost Scenario (with high petrol prices and capital cost parity in 2025) a shift to 100 per cent electric buses costs almost 12 per cent less than continuing to operate ICE buses. Even in the High Cost Scenario a shift to 100 per cent electric buses costs only 10 per cent more than business as usual. This amounts to an increase in cost of only $38 per capita per annum, or $0.72 per capita per week.

In Option 1 (ICE buses) the majority of the cost is found to be in fuel, with maintenance costs and capital costs also being significant. In Option 2, transitioning to 100 per cent electric buses, capital costs are calculated to double. However, fuel costs are reduced, and maintenance costs are reduced. The costs of battery replacement are relatively small.

The bus fleet rapid charging infrastructure was projected to cost a total of $271 million (discounted at 8 per cent), or $0.81 per annum, per capita. This cost is assumed to be incurred progressively over time, in proportion to the logistic curve assumed for the transition to electric buses. Even given the conservative cost assumptions applied, this cost is found to be small compared to the total cost of the bus fleet itself.

These results suggest that a transition to 100 per cent electric buses may cost only slightly more than operation with ICE buses, and may cost significantly less. This indicates that it may be commercially desirable to transition to electric buses in the near future.

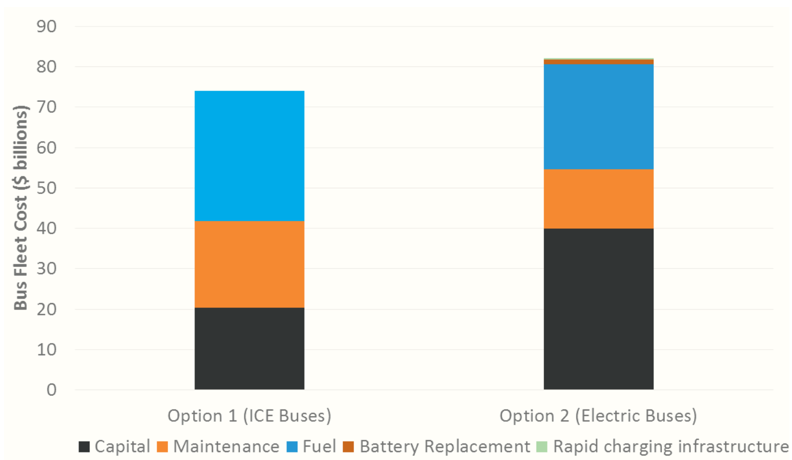


Figure 28 - Bus fleet costs (Net Present Value of total cost during 2015 to 2035) for the High Cost Scenario

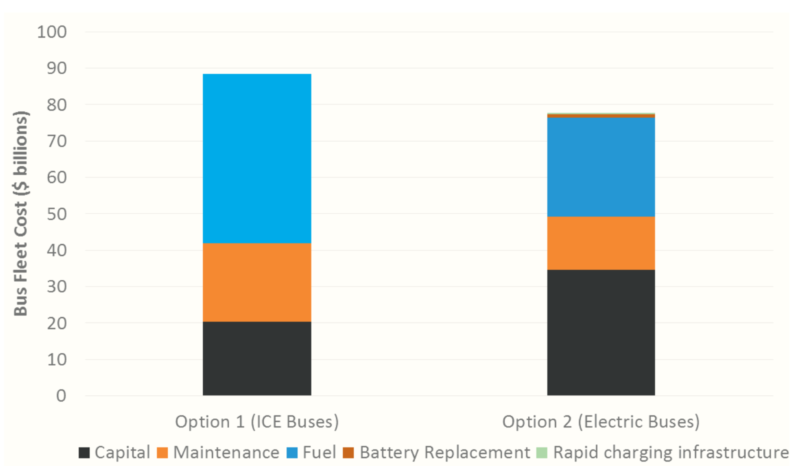


Figure 29 - Bus fleet costs (Net Present Value of total cost during 2015 to 2035) for the Low Cost Scenario. "Fuel" costs in Option 2 include the purchase of renewable electricity to operate buses.

Policy Responses

Policy Responses

7.1 Policy options

Policy options for electric vehicles need to be designed to address the various barriers to the uptake of EVs. The main barriers blocking the greater adoption of EVs in Australia include:

- lack of awareness
- perceived range anxiety
- perceived high upfront cost

There are a range of policy options to address the above barriers to adoption and support the uptake of electric vehicles. Options include:

- Educational programs and fleet trial programs, to raise awareness of the high quality performance, lower operating cost, convenience and substitutability of electric cars.
- Requiring that new car parks and apartment buildings are designed in "readiness" for electric car charging infrastructure retrofit (perhaps through inclusion of appropriate conduits).
- Promoting and supporting car share schemes (such as Go-Get, CarNextDoor, and Flexicar), which increase individual car utilisation rates, and therefore favour electric cars (due to their low operating costs). These schemes could be supported by city councils by providing dedicated parking spaces, and facilitating the installation of electric charging facilities for those spaces, for example.
- Provision of public charging infrastructure, and provision of reserved parking spaces for electric cars
- Promoting or supporting installation

Figure 30 – This car parking sign in Oslo, Norway indicates that parking is reserved for EVs only (Source: Stephen Bygrave)

of public charging infrastructure by private businesses

- Introduction of progressively stringent car emissions standards
- Reducing or removing taxes on the import of electric vehicles
- Lower or no registration fees for electric vehicles
- Access to transit lanes for electric vehicles.

Table 6 and Table 7 summarise various specific policies and incentives that have been implemented in other countries to promote uptake of electric vehicles, and could be considered for implementation in Australia.

Table 6. Key of incentive types

Incentive Types					
Direct financial subsidies or support	Indirect financial incentives: tax or fee reduction	Support on the road: congestion, tolls, restricted lane access	Support for parking costs or infrastructure	Support for charging fees or equipment	Support for electricity bills

Table 7. International Policy Incentives

Country	National Incentive	Regional/ Local Incentive	Infrastructure	RD & D
Canada		-Ontario- Purchase rebate of $8 500 based on battery performance. -British Colombia- Rebates of $5 000 for car purchase & $500 for home charging infrastructure. -Quebec- Rebate of up to $8 000.	(regionally implemented)	-Research undertaken by Clean Transportation Systems Portfolio. -Clean Energy Fund RD &D.
China	-Government subsidy of about $12,000 per vehicle. -Target of 5 million EVs or fuel-cell vehicles by 2020.	-Beijing, Shanghai & Shenzhen- Purchase subsidies of up to $11,000. -Shanghai- $7,300 additional subsidy & automatic registration. -Shenzhen - Free tolls, municipal fleet, free charging. -Hong Kong - lower registration fees and no fee in first year.*	$4 billion for charging infrastructure (and electric car uptake promotion).	-$10 billion for technology and manufacturing support. -$5 billion for demonstration projects .
Denmark	-Exemption from green ownership fee $1 800. -Exempt from the new car registration tax (105% tax on cars valued at up to $14,000 and 180% thereafter.	Copenhagen- Free parking.*	A portion of $106 million to develop charging infrastructure.	$3 million electric car pilot scheme. Electric car integration into the smart grid.

- * Potential for application in Australia

Country	National Incentive	Regional/ Local Incentive	Infrastructure	RD & D
France	-Purchase bonuses of $9,000 for cars 0-20g CO2/ km. -Exemption from company car tax.* -Lower off peak electricity rates.*	Paris- Autolib car sharing scheme.*	Part of $681 million for infrastructure projects, $75 million for equipment and installation.	$212 million for car RD&D.
Germany	-Exempt from road taxes for 10 years. -Transferable license plates. -Benefits from electricity supplier*.	-Berlin- Innovative charging data and mapping technology. -Hamburg – Cross-sector collaboration.	-Four regions to showcase electric cars.* Charging point mapping.*	RD&D for batteries, drive trains and information and communication technology.
Japan	Support for 1/2 of the price gap between electric car and equivalent ICE car, up to $10,800. Tax reductions.	-K.P.G- Half price tolls and parking.* -Goto Islands- "Driving Tours of the Future".*	-Support for 1/2 the cost of EVSE up to up to $16,200. -Japan now has more EV charging points that petrol stations.	Focus on fast chargers and infrastructure RD&D.
Netherlands	-Policy of 100 per cent EVs by 2025. -Tax reduction of 10-12% of net investment on car. -Reduced annual circulation tax and congestion taxes. -4% "bijtelling".	-Rotterdam – $15 million funding for incentives. -Amsterdam- Purchase subsidies and Car2go share scheme.* -BrabantStad – Investments and tax benefits of $151 million.	-Incentives to support charging points. -36% of investment costs are deductable for companies.	Battery R&D.
Norway	-Electric cars offered exemptions and deductions on registration, purchase taxes. No congestion or toll road charges. 50% discount on company car tax.* -A recent plan proposes that all new cars, vans and buses should be zero emissions by 2025.	Oslo- Free park & charge. Access to bus lanes.		

Country	National Incentive	Regional/ Local Incentive	Infrastructure	RD & D
Spain	Subsidy of 25% of pre-tax car price up to $9,000 until end of 2012. Additional incentives worth $3,000 available.	Barcelona – Tax benefits, free charging at municipal points, free parking. 2% of new car parks reserved for electric cars.*	Incentives for charging infrastructure from national and regional government collaboration.*	Five RD&D programs.
Sweden	'Super green car rebate'. $6,800 for private cars and 35% of the premium cost for company fleets, car pools etc. No circulation tax for first five years.*	Stockholm- 296 organisations and companies committed to purchase 1250 electric cars over four years.*	Green highway from Sundsvall, Sweden – Trondheim, Norway using some free and fast charging stations.	$3.8 million for battery R&D.
United Kingdom	Electric car offered a rebate of 25% of the car's value up to $9,400. Annual circulation tax exemption. Exempt from company car tax, luxury car tax, road tax and "van benefit charge".	London - Electric cars exempt from congestion charge.*	-$68 million for charging points until 2015. -50-100% grants for charging infrastructure cost and installation.	60 low-carbon car R&D projects.
United States	Tax credits for new electric cars based on battery performance of up to $8,300 (for first 200,000 sold).	California- Additional $2 800 tax rebate. Extended battery guarantees, access to high occupancy lanes, discounts on insurance, sales tax and registration fees.* Electricity bill discounts, reduced off-peak rates, free parking (localities e.g. Los Angeles and Santa Monica).*	Tax credits for EVSE installation up to $3 300. Emphasis placed on slow chargers.	In 2012 almost $700 million was budgeted for RD&D. Tesla Motors.

*Indicates potential in Australian context.

All values are converted into Australian Dollars using February 2014 exchange rates.

7.1.2 Car-share, Ride-share, and Autonomous Vehicles

Car-share and ride-share services connect people with drivers and vehicles when and where they need it. After humble beginnings in the 1990s, uptake of car-sharing (such as GoGet, CarNextDoor, and Flexicar) has grown rapidly in the US, Europe, and Australia and enabled many households to reduce the number of vehicles they own without compromising their mobility. More recently, ride-sharing services, such as Uber, have emerged on the scene and seem set to further decouple use of private vehicles from their ownership.

Car-share and ride-share services essentially deliver "mobility on demand", thereby helping people to avoid the fixed costs (and hassle) involved in owning a private vehicle. By breaking the link between private vehicle ownership and use, they enable more households to live with fewer vehicles [37]. Car-share and ride-share effectively take the fixed (sunk) costs of vehicle ownership and turn them into a marginal cost that is incurred for every journey.

Research suggests that when confronted with these costs, many people respond by reducing both their levels of vehicle ownership and also their demand for vehicle travel [38]. Households which previously felt compelled to own additional vehicles "just in case" find that car-share and ride-share services allow them to maintain mobility without owning vehicles.

Many cities internationally are increasingly grasping the wider benefits of car-share and ride-share services. In New Zealand, for example, Auckland Transport (AT) has recently invited tenders for the delivery of a car-share scheme [39]. The successful tenderer is expected to work with AT to deliver the car-share scheme, with the latter supporting via the provision of convenient on-street parking. AT has also expressed a preference for an all-electric car-share scheme, where re-charging occurs by way of public on-street charge points.

7.1.3 Autonomous vehicles

While the technology is less well-developed and not currently in wide-spread use, autonomous vehicles (also known as "driverless cars") may also expand people's access to vehicles "on demand". If and when they are deployed, autonomous cars are likely to further reduce the costs of taxi services beyond that achieved by ride-share services (which still require a driver). In this way, autonomous vehicles - when they become widespread - may reduce private car ownership.

When considered collectively, car-share, ride-share, and autonomous vehicles are complementary technological developments which seem likely to transform the way private vehicles are owned, managed, and used. Moreover, by concentrating more vehicle travel into fewer vehicles, they increase the relative cost-advantages of EVs. Indeed, most of the autonomous vehicles currently under development appear to be electric [40].

7.1.4 Infrastructure Priorities

Most Australian cities have levels of vehicle ownership and use that are high by international standards [41]. Evidence suggests, however, the per capita demand for vehicle travel in Australian cities has plateaued and may even be in decline [42]. Similar trends are being observed in a large

Figure 31- An EV car share in Vancouver (Source: Stephen Bygrave)

number of OECD countries [43].

Australia's high levels of vehicle ownership and use have eventuated partly in response to the infrastructure priorities of federal, state, and local governments. Indeed, policy settings have typically sought to meet the growing demand for vehicle travel through the provision of more (often highly subsidised) road infrastructure. The failure of several major road tolling projects suggests people's willingness-to-pay for vehicle travel may be less than previously assumed [44].

Now may be an opportune time for policy-makers to re-visit infrastructure priorities and increase investment in non-car transport modes. At the federal level, the most recent budget appears to shift investment away from rail and into road infrastructure, with the former's share of the budget declining from 20 per cent in 2013-14 to less than 5 per cent by 2017-18 [45]. Federal transport priorities therefore seem unlikely to support a transition to a zero carbon transport system.

There are opportunities to prioritise infrastructure investment that supports a shift to a zero carbon transport system. In a previous study, for example, BZE investigated the potential benefits of a high speed rail (HSR) link connecting major urban areas on Australia's east coast [3]. While the HSR network had an estimated to cost $84 billion, it was also expected to generate positive operating revenue of approximately $4.6 billion p.a. and return a positive NPV (assuming 4 per cent discount rate) after 40 years. By improving non-car transport options within and between regions, projects like HSR would complement the shift to 100 per cent EVs.

Many cities in Australia currently have a number of unfunded PT infrastructure projects for which federal funding would be welcome. Brisbane's heavy rail network, for example, is relatively constrained in the inner-city. Without investment, rail will be unable to accommodate projected growth in demand over coming decades. Other cities, such as Sydney, Melbourne, Perth, and the Gold Coast are considering investment in both heavy and light rail networks.

In this context, there seems to be scope for re-prioritizing the transport infrastructure investment priorities of federal and state governments so as to support the transition to a zero carbon urban transport system.

7.1.5 Urban policy

Urban policy settings could seek to reduce costs of transitioning to a zero carbon transport system by reducing Australia's dependence on private vehicles.

Travel is a "derived demand". This means that demand arises primarily in response to the demand for other activities, such as work, shopping, and social activities. As a result, the amount of vehicle travel generated within an urban area will tend to partly reflect its urban form, which in turn is influenced by policy settings.

U.S. research suggests certain urban forms can reduce the demand for vehicle travel in the order of 25 per cent [46, 47]. Other research suggests the urban form attributes which lead to reduced levels of vehicle ownership and use are relatively complementary, or "synergistic" [48]. By ensuring land use and transport policies maximise accessibility for non-car modes, Australia cities can reduce the demand for vehicle ownership and use, and thereby reduce the costs of transitioning to a zero carbon urban transport system in the future.

Policy-settings adopted in many Australian cities may even be unintentionally supporting more vehicle-dependent urban form and thereby undermining efforts to reduce carbon emissions [49, 50, 51]. Examples include rules on minimum apartment sizes, building height limits, floor-area ratios, and minimum parking requirements. These policies should be re-examined to ensure they support efficient and resilient land use and transport outcomes.

Policies used to funding and price transport infrastructure are also relevant. In many places, transport infrastructure is funded in ways that provides no ongoing incentive for managing the resulting demand for vehicle travel. Similarly, there may be opportunities for policy-makers to adopt user charges that are more directly linked to demand, such as annual parking levies and time-of-use road pricing [52].

Conclusions

Conclusions

Electric vehicles are a zero emissions transport technology. Charged from renewable electricity, and with no tailpipe emissions, EVs are a personal transport solution that can help address climate change while also delivering a range of benefits.

EV technology, especially batteries, is advancing rapidly and prices continue to fall. We are rapidly approaching a cross-over point where the lifetime costs of ICEs are greater than that of electric cars. Moreover, there has been an explosion in the development of a diverse range of electric personal mobility devices, such as electric bicycles and scooters. The transport sector is electrifying and diversifying, all at the same time.

EVs provide the opportunity for energy freedom. On a national level, EVs mean energy independence, with Australia no longer needing to import transport fuel from overseas. On a personal level, EV owners can potentially provide much or all of the energy needed to run their car, for example by charging from a home PV system. The recent significant cost reductions in PV technology create new opportunities. Even with present electricity cost structures, the homeowner with rooftop PV can benefit from using power generated on-site to minimise purchases from the grid. Electric cars charging at home or work during the day can create additional load to absorb excess generation from the PV system.

Data suggests that existing EV technology is able to cover the majority of the trips we typically take in Australia. Supplemented with comprehensive public charging infrastructure including rapid charging options, as assumed in this analysis, EVs are capable of providing the same level of convenience that we currently enjoy, or better. Many of the electric cars coming to market offer the same range as traditional ICEs. For example, the Tesla Model S, with a range of 500km, enables it to travel distances equivalent or greater than similar conventional cars without needing to 'refuel'. The EV revolution is gathering pace, with more affordable mass-produced electric cars with extensive range (over 300kms) all coming on to the market next year (Tesla Model 3, all electric Chevy Bolt, new Nissan Leaf), and all cost competitive with ICEs at around US$35,000.

Modelling conducted for this report shows that the transition to 100 per cent EVs, operating on 100 per cent renewable electricity, is predicted to cost around $20 per capita per week above the business as usual scenario. Under more optimistic assumptions, the costs of the transition are approximately the same as the business as usual scenario. The cost of the shift could be further reduced by adopting complementary policy initiatives at the federal, state, and local government levels, and/or more rapid uptake of electric personal mobility devices. Other OECD countries have implemented a range of policies and incentives designed to stimulate the uptake of EVs.

Most importantly, a shift to 100 per cent EVs for urban travel alone would eliminate six per cent of Australia's greenhouse gas emissions. This would increase to 8 per cent of emissions if regional car travel is also included. This would make a major dent in Australia's emissions and bring Australia closer to a zero emissions economy.

Appendices

Appendix A: Detailed Modelling Assumptions – Car Fleet

This appendix outlines the detailed assumptions and methodology applied in the car fleet model. A high level overview is provided in section.

9.1 Size and Composition of the Car Fleet

The total size of the car[11] fleet between 2004 and 2014 was sourced from the ABS [41]. This was projected forward using a linear extrapolation of historical trends, as illustrated in Figure 32.

11 This analysis applied the definition for a passenger car used by the Australian Bureau of Statistics (ABS) in their 9309.0 - Motor Vehicle Census [41]. A passenger car is considered to be any motor car constructed primarily for the carriage of persons and containing up to nine seats (including the driver's seat). This category includes cars, station wagons, four-wheel drive passenger cars and forward-control passenger cars. Campervans are excluded.

The same total car fleet projection was applied in both Option 1 and Option 2, i.e. the model assumes no change in car ownership and use. The car fleet size was projected forward to 2035, to allow calculation of costs over the twenty year evaluation period. In Option 2, a transition to 100 per cent electric cars was assumed by 2025. The operation of this fleet for a further ten years (to 2035) was quantified and compared with costs in Option 1 (business as usual) to ensure that the benefits of lower fuel costs and lower operations and maintenance costs from electric cars were captured within the study timeframe.

9.1.1 Option 1 – Continuing operation with ICEs

For Option 1, the number of ICEs entering the fleet each year was calculated as per the equation

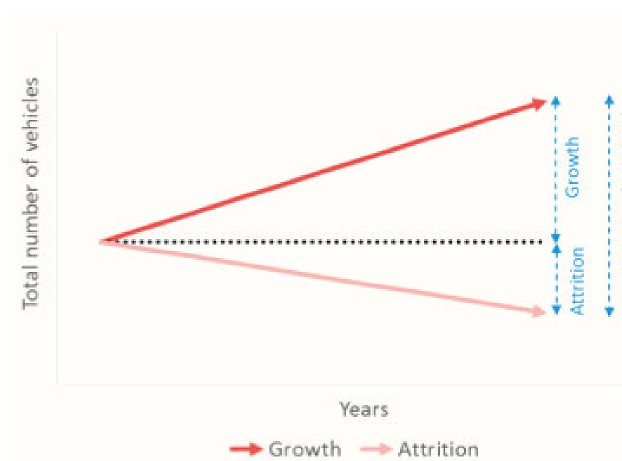


Figure 33 - Illustration of calculation for new cars entering the fleet each year (applied in Option 1 – BAU)

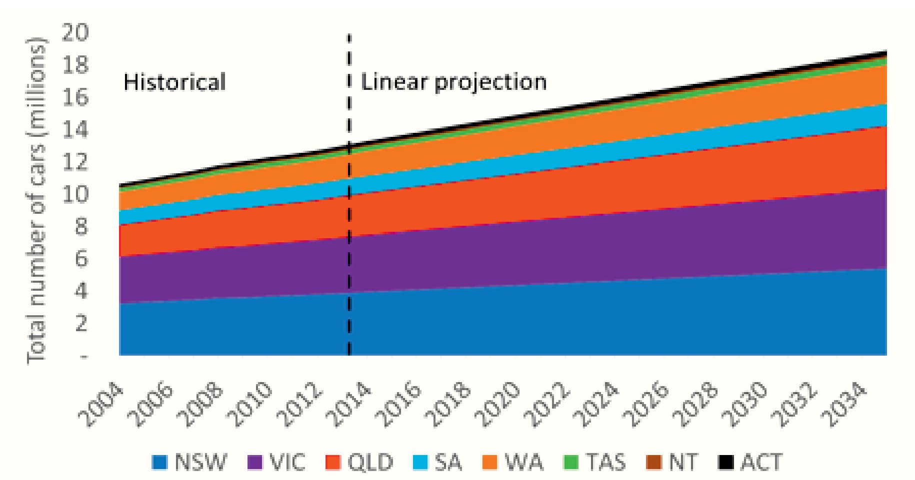


Figure 32 - Size of car fleet in Australia (historical and projected)

below. The number of cars entering the fleet between two consecutive years is equal to net growth plus the number of cars leaving the fleet. This is illustrated in Figure 33.

Data from the ABS indicates a typical annual attrition rate of 4.5 per cent [41], which was applied. Growth each year was calculated from the change in total car fleet size, projected as described above.

9.1.1.1 Used car imports

In Option 1, the number of cars (ICEs) entering the fleet includes:

- New cars purchased from dealers or manufacturers throughout Australia; and,
- Used cars which are imported into Australia.

Used imports constitute a significant proportion of cars entering the fleet, and are significantly less expensive than new cars. This means it is important to quantify the proportion of used imports in order to accurately estimate capital costs in Option 1.

ICEs entering fleet = New cars + Used imports

The ABS publishes monthly sales data on new motor cars sold by dealers and manufacturers throughout Australia [53]. This data was projected forward linearly, and then used to infer the number of imported used cars entering the fleet each year, according to the following equation:

Used imports = Growth + Attrition- New cars

9.1.1.1.1 Car fuel type

Option 1 involves cars fuelled by petrol, diesel and other fuels such as LPG, dual fuel and hybrid, each of which has different costs. The car fuel type distribution for Option 1 was projected using historical data from the ABS [41]. The total number of cars fuelled by petrol, diesel and 'other' fuel types was available from 2004 to 2014, and was subsequently converted to a percentage of the size of the total car fleet for each state and territory. The car fuel type distribution was then projected to 2035 using the average annual change in the percentage composition of cars. The proportion of cars fuelled by petrol and diesel was projected directly, with the percentage of 'other' fuel types inferred as the residual.

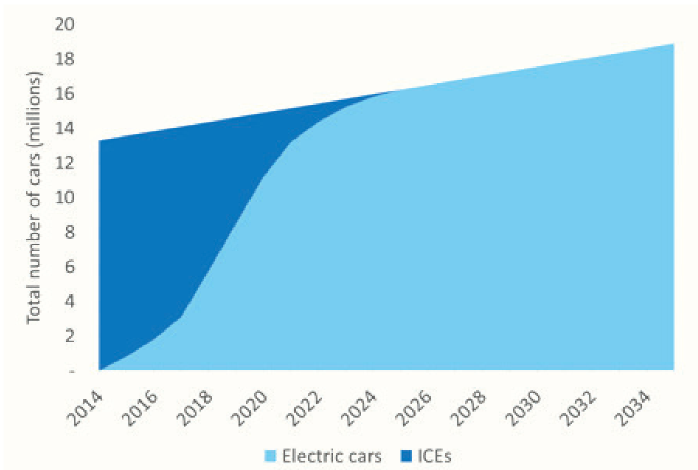


Figure 34 - Proportion of Australian car fleet assumed to transition to electric cars in Option 2 (electric cars)

9.1.2 Option 2 – Transition to 100 per cent electric cars

In Option 2, a logistics function (or S-curve) was used to model the uptake of electric cars over time. The logistics function mirrors the diffusion of innovations theory, which describes the rate at which new technologies are implemented [54]. The remainder of the car fleet was assumed to be ICEs, with the same proportions of petrol, diesel and 'other' fuels as applied in Option 1 (BAU). The logistic function used to model the proportion of electric cars is illustrated in Figure 34.

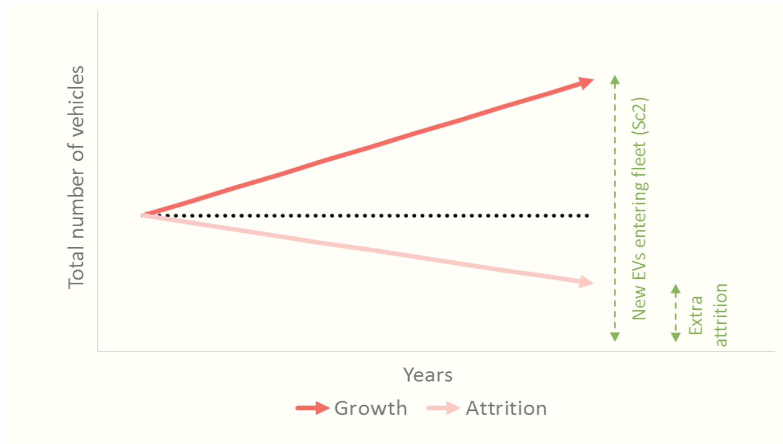


Figure 35 - Option 2 illustration of calculation for new cars entering the fleet each year, if the number of new electric cars entering the fleet exceeds the number of new ICEs entering the fleet in Option 1 in each year

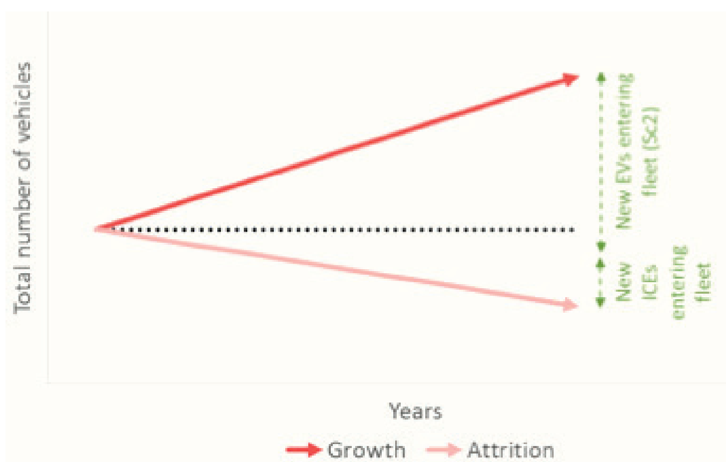


Figure 36– Option 2 illustration of calculation for new cars entering the fleet each year, if the number of new electric cars entering the fleet is less than the number of new ICEs entering the fleet in Option 1 in each year

If the entry of electric cars each year calculated from the logistic function exceeded the number of ICEs entering the fleet in Option 1, additional attrition of ICEs was assumed to occur (beyond the 4.5 per cent annual attrition rate assumed in Option 1), as illustrated in Figure 35. However, if the entry of electric cars was less than the entry of ICEs in Option 1, additional new ICEs were assumed to enter the fleet (to maintain the assumed logistics function). This is illustrated in Figure 36.

In Option 2, it was assumed that no used imported cars would enter the fleet, since all cars entering the fleet are electric cars, which are a relatively new technology, and for which the number of used imports is expected to be minimal. If a significant number of used electric cars are able to be imported, then this would reduce the costs associated with Option 2.

9.1.3 Car size distribution

Vehicles were categorised by size according to the criteria specified by the Federal Chamber of Automotive Industries [55]:

- Small: light passenger, small passenger and compact sports utility car (SUV);
- Medium: medium passenger and medium SUV; and
- Large: large passenger, upper large passenger, people movers, large, and luxury SUVs.

Consumer preferences for different size cars are continuously changing. In line with projections assumed in other studies [56], the car fleet model assumes the market share for cars will trend linearly from the 2008 market share (53 per cent, 24 per cent and 24 per cent for small, medium, and large cars respectively) towards an equilibrium market share of 60 per cent, 30 per cent and 10 per cent respectively by 2020. These market shares are assumed to apply to all Australian states and territories and are listed in Table 8.

9.2 Vehicle Kilometres Travelled

Vehicle kilometres travelled (VKT) is defined as the average distance travelled by registered cars per year, per car. Historical VKT data was sourced from the ABS [9]. It was found that VKT per car per year has declined approximately linearly over time for all Australian states and territories. Hence,

	Proportion of Market Share in Each Year			
	2008	2020	2025	2035
Small	53%	60%	60%	60%
Medium	24%	30%	30%	30%
Large	24%	10%	10%	10%

Table 8 - Car Size Market Share Projections

v

it was assumed that this trend will continue throughout the evaluation period of the study.

For each state or territory, projections were based on historical data from the years 2004-2007, 2010 and 2012 projected linearly to 2035. The results for these projections are tabulated below. These VKT projections were assumed to apply to all small, medium and large cars.

VKT projections were combined with car fleet size projections to obtain projections for the total kilometres travelled for each state and territory. Despite the projected decline in VKT, the projected increase in the number of cars causes total kilometres travelled for each state and territory to increase over time from 182 billion kilometres per year in 2014 to 212 billion kilometres per year in 2035. This is equivalent to a 0.7 per cent increase in total VKT p.a.

9.3 Capital Cost Assumptions

9.3.1 New car capital costs

New ICE car capital costs were sourced from the RACQ [57]. The capital costs of popular small, medium and large ICE cars were averaged to obtain capital costs by car size, as listed in Table 10. Capital costs were assumed to apply to ICE cars in all Australian states and territories, and were assumed to remain constant in real terms between 2015 and 2035 due to the fact that ICE cars are a mature technology.

State / Territory	2004	2012	2025 (Projected using linear model)	2035 (Projected using linear model)	Average Annual Percentage Change between 2004 and 2014
NSW	14,500	13,800	12,400	11,200	-0.93%
VIC	14,900	14,200	13,800	13,300	-0.90%
QLD	15,600	14,900	12,400	10,800	-0.85%
SA	14,100	12,800	9,800	8,000	-1.71%
WA	14,500	13,800	13,000	12,400	-0.95%
TAS	13,000	11,600	8,000	5,100	-1.96%
NT	14,900	13,100	11,300	9,600	-2.44%
ACT	15,000	14,300	13,300	12,900	-0.90%
Australia	14,800	14,000	12,400	11,300	-0.10%
Australia (average car kilometres travelled per car per day)	40.5	38.4	34.0	31.0	-0.10%

Table 9 - VKT Projections by State and Territory (car kilometres travelled per car per year)

Car Size	Capital Cost (new vehicles)
Small	$24,949
Medium	$32,988
Large	$37,196

Table 10 - New ICE Car Capital Costs

New electric car capital costs were sourced from analysis by the international consultancy AECOM [56]. The price of new electric cars was averaged from a survey of 34 electric car products released (or due to be released) between 2009 and 2012. As with the capital costs of new ICE cars, new electric car capital costs were assumed to apply to electric cars in all Australian states and territories.

Since electric cars are a relatively new technology, their capital costs are anticipated to decrease over time. A key assumption in the car fleet model is the time when price parity between ICE and electric car is achieved; that is, the year in which the purchase price of electric cars is equal to that of ICEs. AECOM projects that ICE and electric car price parity will be achieved in 2025 [56]; however, CSIRO expects that electric cars will not achieve price parity with ICEs until 2035 [58]. Given the high importance of this assumption, and the significant uncertainty over future electric car capital costs, two possibilities were considered for this modelling. In the High Cost Scenario, ICE and electric car capital cost parity was assumed to occur in 2035. In the Low Cost Scenario, it was assumed that electric car costs reduce much more rapidly, such that ICE and electric car price parity (in terms of capital costs) was assumed to occur in 2025. Capital cost assumptions applied in the High Cost Scenario are illustrated in Figure 37.

Car Size	Capital Cost (used imported vehicles)
Small	$8,000
Medium	$10,578
Large	$11,927

Table 11 - Used Imported ICE Car Capital Costs

9.3.2 Used Imported ICE Car Capital Costs

The assumed prices for used imported ICE cars are listed in Table 11. These are based upon an assumption of a capital cost of approximately $10,000 for a medium car, and maintaining the relative proportional costs between small and large cars as per the new car costs published by the RACQ [57].

9.3.3 Electric Car Battery Replacement Costs

The car fleet model assumes that the battery life of electric cars is ten years, after which electric car

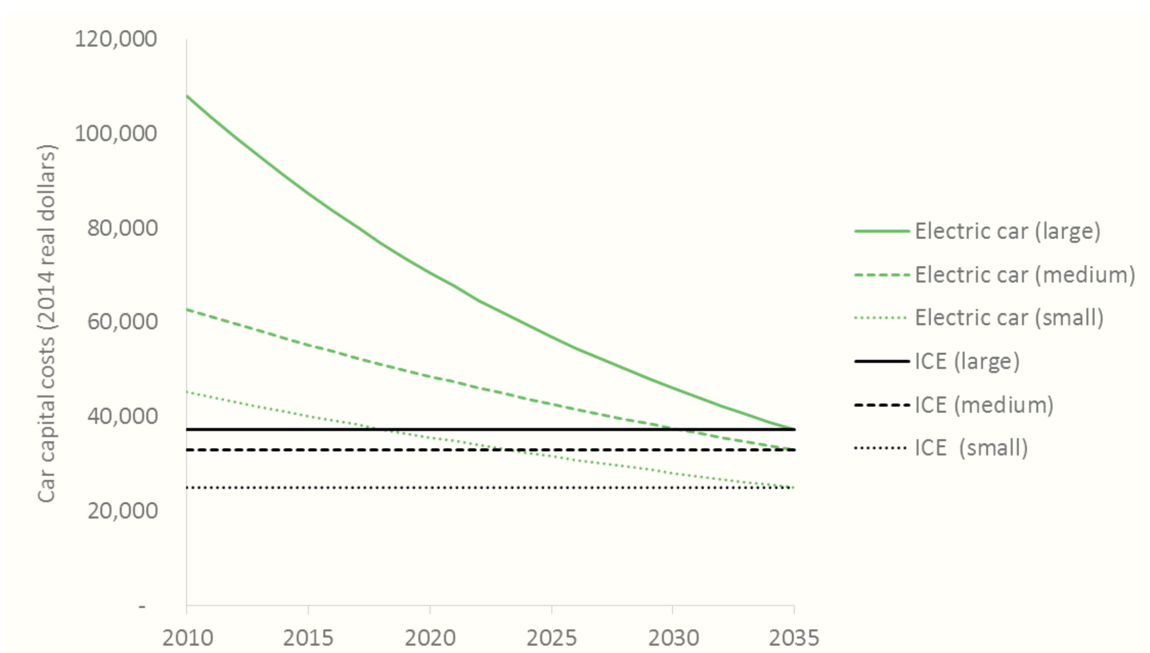


Figure 37 - Car capital cost assumptions (High Cost Scenario)

batteries must be replaced. Therefore, assuming that the car fleet in 2014 contains no electric cars, the cost of replacing electric car batteries is a cost that is only incurred after 2025.

Battery replacement cost projections vary widely, however there exists a strong consensus between industry and research that the price of electric car batteries will decline in the future and most likely by a significant amount. The US Energy Information Administration's 'Annual Energy Outlook' [59] projected two electric car battery price cases: a Reference case and a High Technology Battery case. The Reference case illustrates the most likely decrease in electric car battery price. It considers manufacturing, battery chemistry and charging infrastructure improvements. In this reference scenario, the US EIA projects battery costs of $334/kWh in 2035[12]. This was applied for the High Cost Scenario.

The High Technology Battery case assumes that the program goals established by DOE's Office of Energy Efficiency and Renewable Energy (EERE) are achieved. The High Technology Battery case examines the potential impacts of significant breakthroughs in electric car battery technology.

12 Adjusted to real 2014 dollars.

The US EIA projects that this might reduce the cost of electric car batteries further to $148/kWh in 2035. This projection was used for the Low Cost Scenario.

9.4 Operation and Maintenance cost assumptions

9.4.1 ICE Operation and Maintenance Costs

ICE car operation and maintenance costs include registration, insurance, service and repairs; estimates of these costs were sourced from the RACQ [57]. Operation and maintenance costs of popular small, medium and large ICE cars were averaged to obtain costs by car size. The RACQ quotes operation and maintenance costs for cars which are 1 to 5 years old and assumes that cars travel 15,000 kilometres per year [57]. This is broadly consistent with VKT data from the 9208.0 Survey of Motor Car Use [9].

Other operation and maintenance cost assumptions include:

- 100 per cent of the total cost (including statutory and other on-road costs) of a new car have been financed at an interest rate of 7.45 per cent. A $294 loan application fee and $15.44

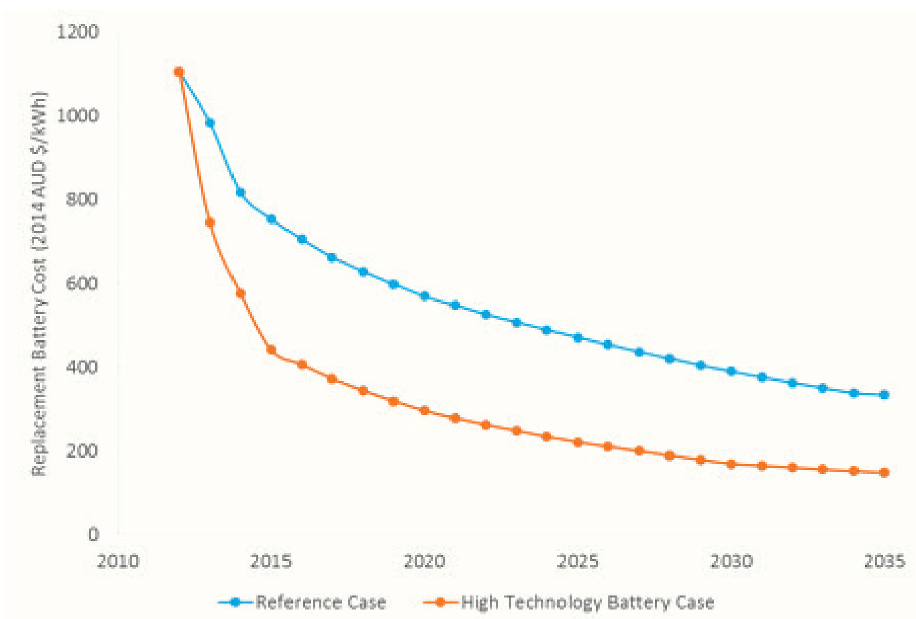


Figure 38. Projected electric car battery replacement costs. Source: [59]

registration of interest and search fee have been included;

- Compulsory Third Party (CTP) insurance is quoted for a driver that is male, 35 years of age, carries $600 basic excess and has an average no claims bonus. Vehicles are garaged at an average risk postcode, are financially encumbered and are for private use;

Car Size	Annual Operation and Maintenance Cost	Operation and Maintenance Cost (c/km)
Small	$3,513	23.43
Medium	$3,698	24.66
Large	$3,572	23.82

Table 12. Annual ICE Car Operation and Maintenance Costs by Car Size

- 4 tyres are replaced every 45,000 kilometres, while 1 tyre is replaced every 5 years due to puncture damage beyond repair; and

- Maintenance costs include servicing according to the manufacturer's schedule, plus any repairs and spare parts. A labour rate of $150.29 per hour has been included.

From these assumptions, the annual ICE car operation and maintenance costs were calculated by car size, as listed in Table 12.

Since ICE cars are a mature technology, operation and maintenance costs were assumed to remain constant in real 2014 dollars throughout the evaluation period of the study, and were applied equally in all states and territories.

9.4.2 Electric car Operation and Maintenance costs

Electric cars generally have lower maintenance costs than equivalent ICEs. Electric car components such as traction motors and controllers require very little maintenance, and electric car brake pads require replacement less frequently than ICE brake pads (due to the use of regenerative braking). Electric cars do not have any oil or oil-filter change requirements, an electric car has fewer moving parts than an ICE, and the electrical components are expected to have a long maintenance-free life [60]. Some studies suggest that electric car maintenance costs are around 25 per cent to 35 per cent less than equivalent ICEs [56, 61, 62]. Others find electric cars may have maintenance costs 50 per cent less than ICEs [63, 64], or perhaps as much as 80 per cent less [60].

For this study, two comparative assumptions have been applied. In the High Cost Scenario, electric car maintenance costs have been assumed to be 75 per cent of those for an equivalent ICE. In the Low Cost Scenario, electric car maintenance costs have been assumed to be 20 per cent of an equivalent ICE. These values exclude a constant maintenance cost of $1,500 per annum applied to all cars for registration and insurance.

9.5 Fuel Cost Assumptions

9.5.1 ICE Car Fuel Efficiency

Historical data on fuel consumption by car type was sourced from the ABS [9]. The data between 1979 and 2012 was used to project the fuel efficiency of an ICE car based upon a linear trend in the fuel efficiency of petrol cars. Diesel and "other" fuel types were based upon a linear trend in the weighted average of all fuel types. This led to an assumption of fuel efficiencies of 11.0 L/100km in 2015, with a moderate reduction to 10.2 L/100km in 2035.

9.5.2 Retail Fossil Fuel Price Projections

Retail fuel prices were projected using a model developed by the Bureau of Infrastructure, Transport and Regional Economics (BITRE) [65] with input data from the International Energy Agency (IEA). The model suggests that retail fuel prices in Australia are affected by several factors. These include:

- The world oil price
- The exchange rate between the Australian dollar and the US dollar
- The fuel excise tax
- The goods and services tax (GST) which is currently 10 per cent in Australia [65].

The model evaluates low, medium and high petrol price scenarios based on Odell's high supply scenario (low prices), IEA's long-run supply forecasts (medium prices) and an adjusted IEA model (high prices) [65]. Retail petrol price predictions are illustrated in Figure 37. All fuel price projections exclude GST and fuel excise taxes.

The medium fuel price projections were applied for the High Cost Scenario, with the high petrol price projection applied for the Low Cost Scenario (where "low cost" refers to a shift to 100 per cent electric cars being comparatively lower cost than Option 1).

For diesel prices, Australian Petroleum Statistics publications by the Bureau of Resources and Energy Economics [66] indicated that the average world price difference between oil and diesel was then US$2.36/barrel in nominal terms between 2010 and 2014. This difference was added to the projected world oil prices in the low, medium and high scenario to project the world diesel price, utilising the same BITRE model applied for petrol prices.

Car Size	2010	2025	2035	Annual % change
Small	0.190	0.178	0.170	0.45
Medium	0.165	0.154	0.147	0.45
Large	0.215	0.201	0.192	0.45

Table 13 - Projected electric car energy efficiencies (kWh/100km) by sizeSource: [56]

9.5.3 Electric car Energy Efficiency

Projected electric car energy efficiencies were sourced from analysis by AECOM [56]. Current electric car energy efficiencies were extracted

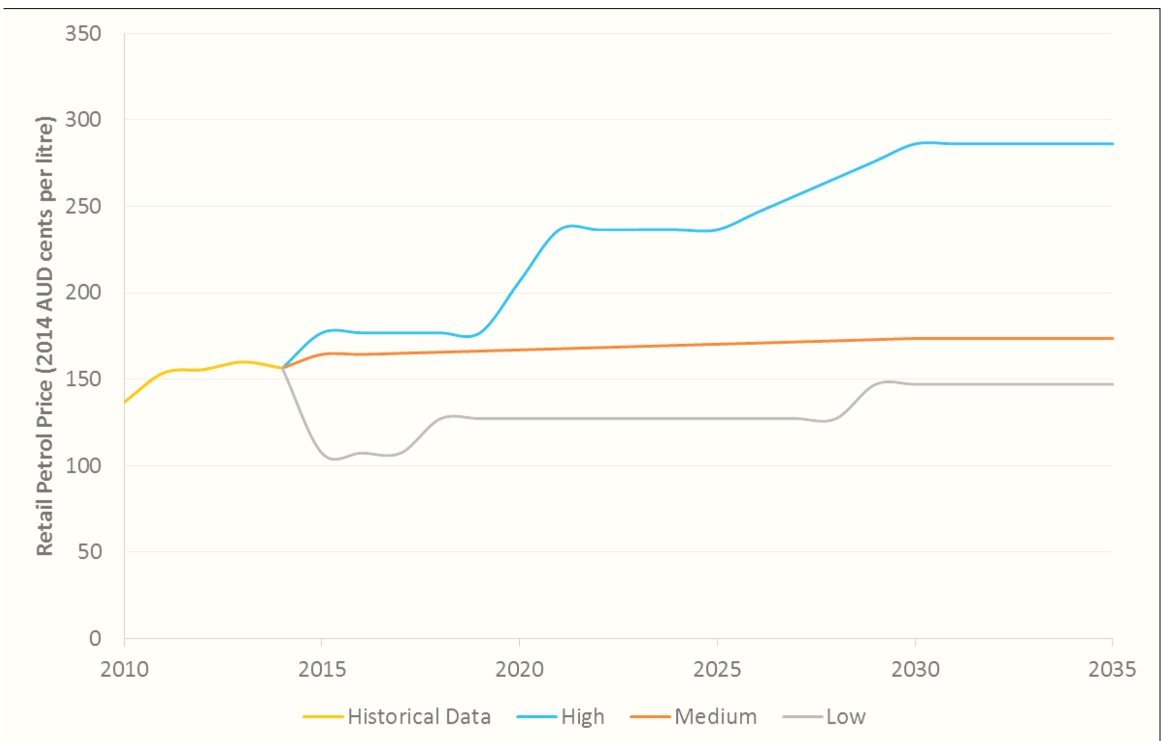


Figure 39. Retail petrol price projections (excluding GST and fuel excise taxes) Source: [65]

from a survey of current and planned electric car models. In line with AECOM's study, the car fleet model assumes that electric car efficiency will improve by 20 per cent between 2006 and 2050. This is equivalent to efficiency improvements of 0.45 per cent per annum.

9.5.4 Price of Electricity

Wholesale electricity price projections for each state/territory were sourced from Beyond Zero Emissions' (BZE) Stationary Energy Plan [1]. This analysis indicated that 100 per cent renewable electricity could be supplied for Australia at a wholesale cost of 12 c/kWh. This value has since been validated by further analysis by the University of New South Wales [21] and a detailed study by the Australian Energy Market Operator (AEMO) [24]. AEMO projected wholesale electricity prices between 11.1 and 13.2 c/kWh in 2030 for a 100 per cent renewable power system. This included necessary augmentations of the transmission network. Therefore an average wholesale electricity price of 12 c/kWh was applied throughout the study period.

Additional retail, network and other costs applied to retail electricity prices were sourced from analysis by the Australian Energy Market Commission [67]. The costs associated with policies designed to promote renewable energy were excluded, since this cost is already accounted for in the increased wholesale electricity cost applied for this analysis. The costs associated with policies designed to promote energy efficiency measures were retained. The resulting retail electricity price projections are listed in Table 14.

These electricity prices provide a conservative estimate. It is likely that time of use tariffs, or other pricing mechanisms, will be applied to incentivise charging of electric cars in off-peak periods. This will mean that electric car charging will typically incur lower than average prices. The additional electrical load from electric

State/Territory	Retail, Network & Efficiency policy costs (c/kWh).	Wholesale electricity price projection (c/kWh)	Retail electricity price projection (c/kWh)
Australia	19.08	12.00	31.08
QLD	19.59	12.00	31.59
NSW	21.49	12.00	33.49
ACT	12.65	12.00	24.65
SA	21.76	12.00	33.76
VIC	17.32	12.00	29.32
TAS	19.48	12.00	31.48
WA	13.26	12.00	25.26
NT	11.09	12.00	23.09

Table 14 - Retail Electricity Price Projections

car charging is also sufficient to meaningfully impact network utilisation, meaning that the c/kWh charge for networks could reduce. These effects have not been taken into account, and as such these estimates of electricity costs are likely to be conservative.

9.6 Greenhouse Gas Emissions

To evaluate the greenhouse gas (GHG) effects of the car fleet in each scenario, the potential GHGs emitted by the car fleet were estimated utilising emissions factors published by the Department of Climate Change and Energy Efficiency [25]. These have been tabulated below according to fuel type.

(BAU) The model assumed that the emissions factors for cars fuelled by 'other fuels' is the same as the emissions factor for LPG. It should be noted these emissions factors are only applicable for carbon dioxide, methane, nitrous dioxide and synthetic gases emitted from the combustion of petrol, diesel and LPG. The radiative effects of indirect greenhouse gases, such as short-lived carbon monoxide and transport-related aerosols, and embodied emissions in manufacturing and distributing the cars are not accounted for in these factors.

9.7 Population Projections

Population projections were sourced from the ABS [68][13]. Australia's population is projected to grow from the present 23 million to more than 28 million by 2025, and more than 33 million by 2035. These population projections were used for calculating per capita costs from the model.

13 The ABS uses the cohort-component method to project population; this method applies assumptions regarding future fertility, mortality and migration to each year of data during the projection period.

9.8 Charging infrastructure

A charging infrastructure model was developed to quantify the costs of deploying electric car charging infrastructure in Australia to support the conversion of the car fleet to electric cars by 2025. The same car fleet and population data, price year, discount rate and evaluation period was used to construct the charging infrastructure model as the car fleet model.

The charging infrastructure model assumes the following:

- Household charging - A Level 2 charger is installed in every house when an electric car is purchased. While electric cars can be charged from a standard 10A circuit (Level 1) it is considered likely that most electric cars will be sold with the inclusion of a Level 2 charging unit [69].

- Public Level 2 charging - One Level 2 public charging unit is assumed to be installed somewhere in an urban area with each new electric car purchase. It is highly uncertain how many public charging units are likely to be installed. However, a proportional increase over time as the electric car fleet increases seems likely, and this modelling applies the baseline assumption of one public charge point per car.

- Rapid charging - Most charging is anticipated to take place in households, with some top-up charging

Fuel	Emissions Factors (kgCO_2 equivalent/L of Fuel)
Petrol	2.47
Diesel	2.90
LPG	1.71

Table 15 - Emissions Factors used to calculate GHG emissions in Option 1

at Level 2 public charging points. However, rapid charging stations are likely to be required to alleviate concerns over car range, and to ensure that users always have access to a rapid recharge if required, especially to enable intercity travel. Therefore, rapid charging stations were included at a rate of one per 79 km2 (the area of a circle with a five kilometre radius) for all urban areas in Australia. This ensures that within urban areas electric car users will typically be within five kilometres (or around a five minute drive) of a rapid charge station. Urban areas were as defined by the ABS [70]. Each rapid charge station was assumed to have 10 rapid charge points available.

The costs assumed for installing charging infrastructure are listed in Table 16. Charging infrastructure costs were assumed to decline over time at a rate of six per cent per year (based upon a halving of cost by 2020 as assumed by AECOM [56]).

Rapid charging infrastructure was also assumed to have an average maintenance and repair cost of $1,900 per annum per rapid charge point [71]. Note that some businesses (such as Tesla) are providing charging facilities at their own expense, and providing this free of charge to their customers. However, this cost remains included in this modelling, since it is a cost incurred during the transition. This modelling does not specify which party incurs each cost (private owners, businesses, city councils and governments, or other).

It was assumed that Level 2 public charging infrastructure would be installed in existing carparks (or greenfield carpark developments, such that they would be developed identically in Option 1 and Option 2), and therefore that no additional land area would be required to be set aside for these charge points.

For rapid charging stations, it was assumed that these would be developed on the sites where petrol stations exist at present (and would be closed in a 100 per cent electric car scenario). The number of rapid charge stations required given these assumptions was found to be far less than the number of petrol stations currently operating in Australia[14]. Therefore, the land on which these extra petrol stations currently reside will become available for other purposes, and the value of that land therefore was quantified as an additional economic benefit in Option 2. The value was quantified using average urban land values published by the ABS[15] [72, 73]. Each petrol station was assumed to occupy a space of 900m^2 (30m by 30m).

14 Based upon a Yellow Pages search for existing petrol stations in each state. This is likely to be a conservative assumption.

15 These are published for Victoria and Queensland. For other states, an average of the QLD and VIC values was applied based upon the relationship between urban land value and population density.

Typical range	In-home Level 2	Public Level 2	Rapid Charge
2014 [69]	$650 to $1,800	$3,550 to $9,225	$29,650 to $80,400
Assumed for 2014	$1,225	$7,375	$569,250
Assumed for 2025	$840	$5,055	$396,184
Assumed for 2035	$327	$1,967	$165,736

Table 16 – Capital cost of purchasing & installing electric car charging infrastructure over time

Appendix B

Appendix B: Bus Fleet Modelling Assumptions

The methodology applied for calculating the cost of an electric urban bus fleet was similar to that applied for the car fleet and is described in more detail below.

10.1 Size of the urban bus fleet

Historical data on the size of the urban bus fleet between 2004 and 2014 was obtained from the ABS [41]. This was projected forward linearly. It was assumed that 75 per cent of registered buses in each state are used for urban public transport services (registered buses as reported by the ABS includes urban buses used for public transport services as well as coaches and school/charter buses, which are not in the scope of this investigation). The number of registered buses assumed to be used for urban public transport has grown from 53,500 in 2004 to 70,600 in 2014. This was projected to grow to 90,700 in 2025 and 109,000 in 2035, based upon the linear trend evident in the historical data.

10.2 Buses entering and leaving the fleet

As for the car fleet model, an attrition rate of 4.5 per cent was assumed for urban buses, based upon data from the ABS [41]. The number of buses entering the fleet was then calculated as the sum of the growth in the fleet, and the replacement of the buses leaving the fleet each year. The urban bus fleet model assumes that all buses entering the fleet were purchased new from manufacturers (no second hand market).

As for the car fleet model, the same logistic function was applied to model the transition to electric buses in Option 2. Due to the need to remain within maximum regulatory axle limits, the passenger capacity of electric buses is slightly smaller than standard buses. For this modelling, we have assumed the existing bus fleet is replaced with 10 per cent more electric buses, to ensure the total passenger capacity of the urban bus fleet is maintained.

10.3 Fuel type distribution

For Option 2, all buses entering the fleet were assumed to be battery electric. For Option 1, the 2014 composition of the bus fleet by fuel type was assumed to apply in future years (19 per cent petrol, 77 per cent diesel and 4 per cent 'other' fuels, sourced from the ABS [41]). For this modelling it is assumed that 'other fuels' refers mainly to compressed natural gas (CNG).

10.4 Bus capital and maintenance costs

The capital and maintenance costs for buses were sourced from BYD Auto, a manufacturer of electric buses [74, 75], and are listed in Table 17. It was assumed that petrol buses have the same capital and maintenance costs as diesel buses.

As is illustrated in Table 17, electric buses currently have a significantly higher capital cost than fossil fuel buses. As for the car fleet model, the modelling assumes that capital price parity will be achieved between electric buses and diesel buses by 2035, via a learning curve. As a mature technology the capital cost of ICE buses is assumed to remain constant between 2015 and 2035.

As for electric cars, a replacement of the battery in electric buses was costed into the model at ten years of age for each bus. It was assumed that battery replacement costs are equivalent to 10 per cent of the capital cost of the bus.

10.5 Fuel costs

Fuel efficiencies for fossil fuel buses and electric buses were assumed to remain constant over time [74, 75], as illustrated in Table 18.

The same fuel price projections used for petrol, diesel and electricity in the car fleet model were implemented for the urban bus model. In both scenarios, urban buses were assumed to each travel 240km per day, and be in service an average of 280 days per year.

10.6 Bus charging infrastructure

It was assumed that rapid charging stations would be installed to support an electric bus fleet, allowing fast recharging of buses during the day. Rapid charging units capable of charging an electric bus in 10 to 20 minutes were conservatively assumed to cost ten times the cost of a typical electric car rapid charge unit ($550,250 per charge point). Costs were projected to reduce over time at a learning rate of 6.1 per cent per annum (as for the electric car fleet). A maintenance and repair cost ten times that for electric car rapid charge units was also assumed for electric bus rapid charge units ($19,000 per annum, per charge point). An electric bus rapid charge station is assumed to comprise of 10 rapid charge points (allowing ten buses to recharge simultaneously).

A circular area with a radius of 15 kilometres was applied between bus charging stations, to determine the number of charge stations required by 2025. This leads to a total of 66 rapid charging stations being installed nation-wide in urban areas (17 in New South Wales, 16 in Victoria, 17 in Queensland, 5 in South Australia, nine in Western Australia, three in Tasmania, and one each in the Northern Territory and ACT). These charging points would naturally be concentrated in the larger urban areas in each state, where the majority of the urban bus fleet is located.

Fuel Type of Bus	Capital Cost in 2012 (2014 AUD per Bus)	Maintenance Cost in 2012 (2014 AUD per Bus per Year)
Diesel/Petrol	$353,120	$25,223
CNG	$454,012	$21,019
Electric	$655,795	$12,611

Table 17 – Capital and Maintenance Cost of Electric and ICE Buses in 2012 (adapted from BYD Auto, 2012)

Type	Fuel Efficiency
Diesel/Petrol	45L/100km
CNG	111.87L/100km
Electric	120kWh/100km

Table 18 - Fuel Efficiency of Electric and ICE Buses Sources: [74, 75]

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- **A shift to 100 per cent electric vehicles would eliminate at least six per cent of Australia's greenhouse emissions.**

- **Electric vehicles are more convenient.**

- **A rapid shift to electric vehicles operating on 100 per cent renewable electricity is both realistic and affordable.**

- **Costs could be even lower if we adapt transport behaviours to reduce car ownership.**

- **A rapid shift to electric buses operating on 100 per cent renewable electricity is also feasible, and affordable.**

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