Australia's National
Science Agency

Electric vehicle projections 2021

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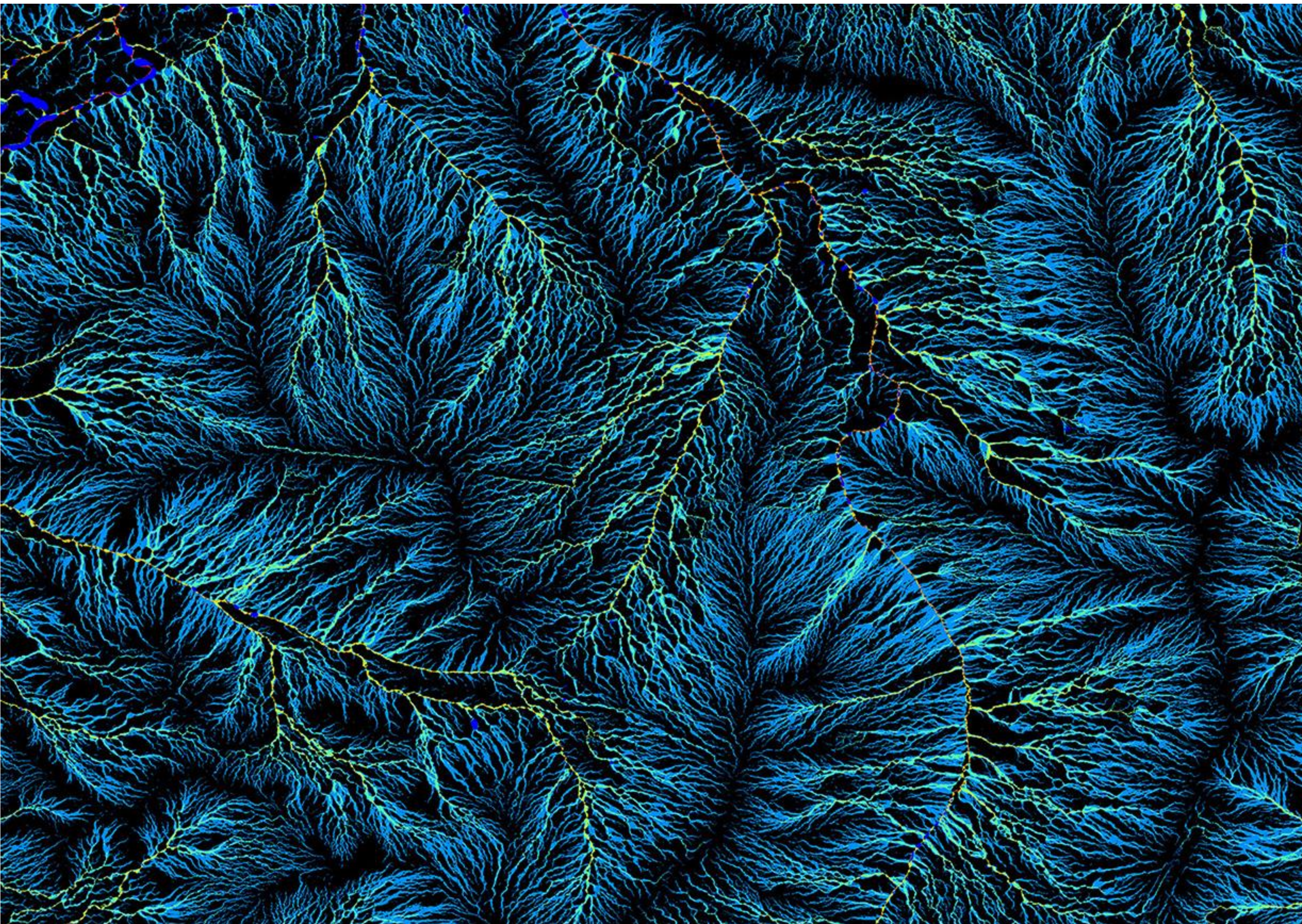

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Acknowledgments

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Executive summary

This report was commissioned by AEMO to provide a record of the methodology, assumptions and outputs of electricity vehicle projections provided by CSIRO to support their planning and forecasting tasks. Electric vehicles projections have been provided for five scenarios: Slow Growth, Current Trajectory, Sustainable Growth and Export Superpower and a Rapid Decarbonisation sensitivity case. Compared to previous projections by CSIRO, this forecast set has a stronger emphasis on net zero greenhouse gas emission targets for Australia of which the road sector would be expected to contribute. The set reflects the outcomes of an updated scenario development process by AEMO with strong stakeholder engagement and recognition of the widening embrace of net zero targets at different levels of government and in the corporate community.

Another major change in the external environment is the announced plans of a significant proportion of global vehicle manufacturers. In recognition of the collective emission targets of many countries, the vehicle manufacturers have outlined plans for the eventual discontinuation of the design or manufacture of new internal combustion vehicles with dates ranging from 2030 to 2050.

These two developments have meant there are more scenarios (Net Zero, Sustainable Growth, Export Superpower and Rapid Decarbonisation) where the fleet completely transforms to either battery or hydrogen electric vehicles. This is driven by a combination of a global reduction in the availability of internal combustion vehicles for sale and the possible removal of internal combustion vehicles from the fleet to meet local targets. The scenarios explore the significant uncertainty in the timing of this fleet transition.

While the projected share of hydrogen vehicles is generally low reflecting their higher cost, lower energy efficiency and less developed fuel supply chain, the Export Superpower scenario presents an opportunity to explore a deeper level of uptake of hydrogen vehicles. In this scenario, hydrogen is assumed to be the dominant fuel for large long-haul trucks and make the greatest inroads into the lighter vehicle market.

Projected electricity consumption from battery electric vehicles is lower in these projections than previous projections by CSIRO. This reflects two COVID-19 related impacts. The first is lower immigration, driving lower population growth, reducing the number of vehicles required in the fleet relative to projections based on pre-COVID-19 population projections. The second is the development of working from home arrangements during COVID-19 and the role of telepresence more generally in reducing greenhouse gas emissions. Under these developments, lower travel per day is assumed (although this still represents a recovery relative to 2020-21).

1 Introduction

Each year, AEMO requires updated projections of electric vehicle adoption and operation of electric vehicle chargers for input into various planning and forecasting tasks. CSIRO has been commissioned to provide electric vehicles projections for five scenarios: Slow Growth, Current Trajectory, Net Zero, Sustainable Growth and Export Superpower and a Rapid Decarbonisation sensitivity case. These are described further in the body of this report.

The report is set out in five sections. Section 2 provides a description of the applied projection methodology. Section 3 describes the scenarios and their broad settings. Section 4 outlines the scenario assumptions in detail and the projections are presented in Section 5.

2 Methodology

2.1 Adoption projections method overview

The projections undertaken are for periods of months, years and decades. Consequently, the projection approach needs to be robust over both shorter- and longer-term projection periods. The longer term adoption projections are based on a fundamental model of relevant drivers that includes human behaviour and physical drivers and constraints. While these models are sound, long term adoption models can overlook short term variations due to imperfect information, unexpected shifts in key drivers and delays in observing the current state of the market. To improve the short-term performance of the adoption models, the approach should ideally include a second more accurate shorter-term projection approach to adjust for short term variations in the EV market.

Short term projection approaches tend to be based on extrapolation of recent activity without considering the fundamental drivers. These include regression analysis and other types of trend analysis. While trend analysis generally performs best in the short term, extrapolating a simple trend indefinitely leads to poor projection results as fundamental drivers or constraints on the activity will assert themselves over time, shifting the activity away from past trends.

Based on these observations about the performance of short- and long-term projection approaches, and our requirement to deliver both long and short term projections, this report applies a combination of a short-term trend model and a long-term based transport demand and technology adoption model.

Other than population, economic growth and assumptions about road vehicle demand, CSIRO made no special allowance in the projections for COVID-19 pandemic impacts. Historical data suggests electric vehicle sales were not impacted in 2020 (despite national vehicle sales of all vehicles falling significantly).

2.1.1 Trend model

For the period between June 2019-20 and June 2021-22, trend analysis is applied to produce projections based on historical data. The ABS motor vehicle census[1] is applied and is considered the most appropriate data set to capture current vehicle numbers, as alternative data sets appear to contain missing data. CSIRO adjusts the sales data from other sources (e.g. the FCAI VFACTS) to align with the identified ABS EV fleet.

The EV trend is estimated as a linear regression against a minimum of 3 years of state annual sales data or up to 5 years for regions where the sales were too volatile to rely too heavily on only recent data. A separate regression is run for plug-in hybrid and battery electric vehicles (PHEVs

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[1] Available at: https://www.abs.gov.au/statistics/industry/tourism-and-transport/motor-vehicle-census-australia

and BEVs). Figure 2-1 shows the projections from the trend analysis. The ACT has experienced a recent jump in sales reflecting its introduction of the largest stamp duty rebates available in Australia for electric vehicles.

The trend model also applies some variation between scenarios in the short-term to capture uncertainty during this period. The Current Trajectory and Net Zero scenarios assume the underlying trend remains unchanged while the trend for Slow Growth is adjusted downwards by 10% and the trend for the remainder of the scenarios is adjusted upwards to a maximum of 20%. This captures the potential for stronger non-linear growth trends in the short term. The ranges are based on the author’s judgement of the degree of upside and downside uncertainty in the trend.

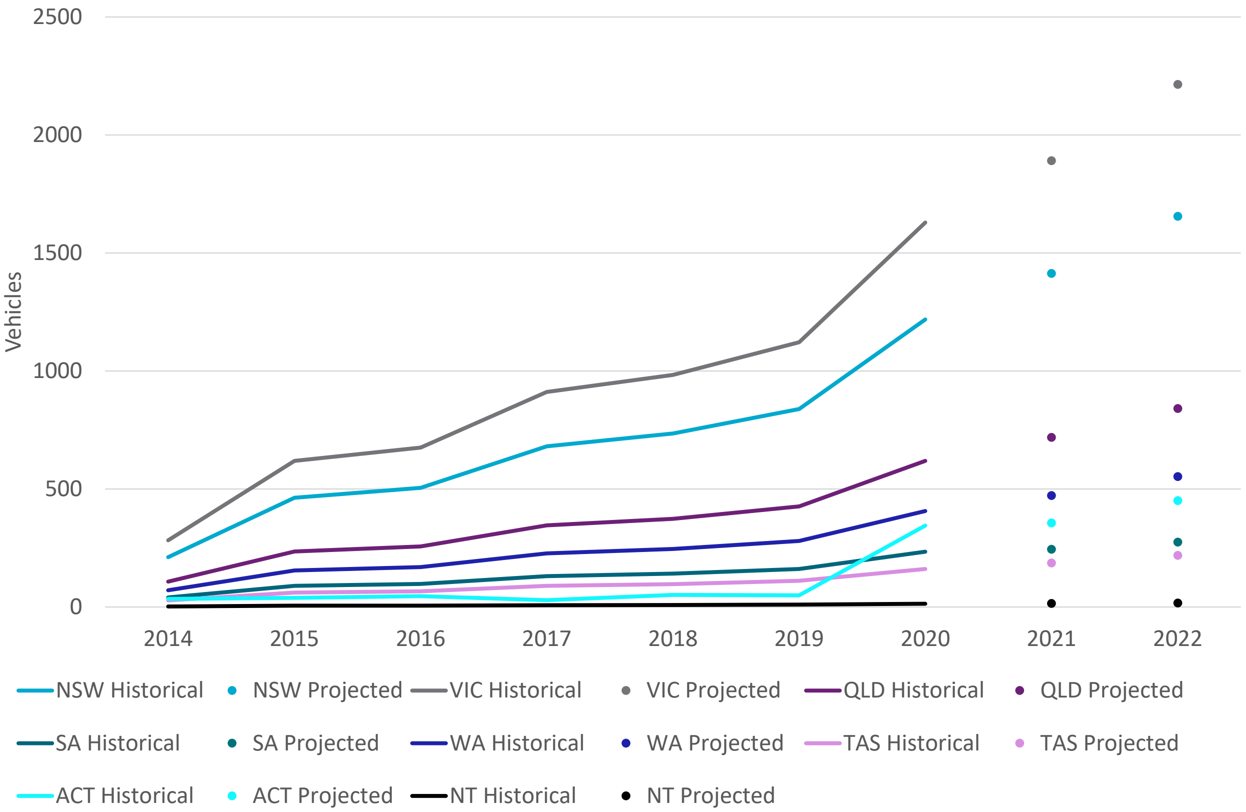


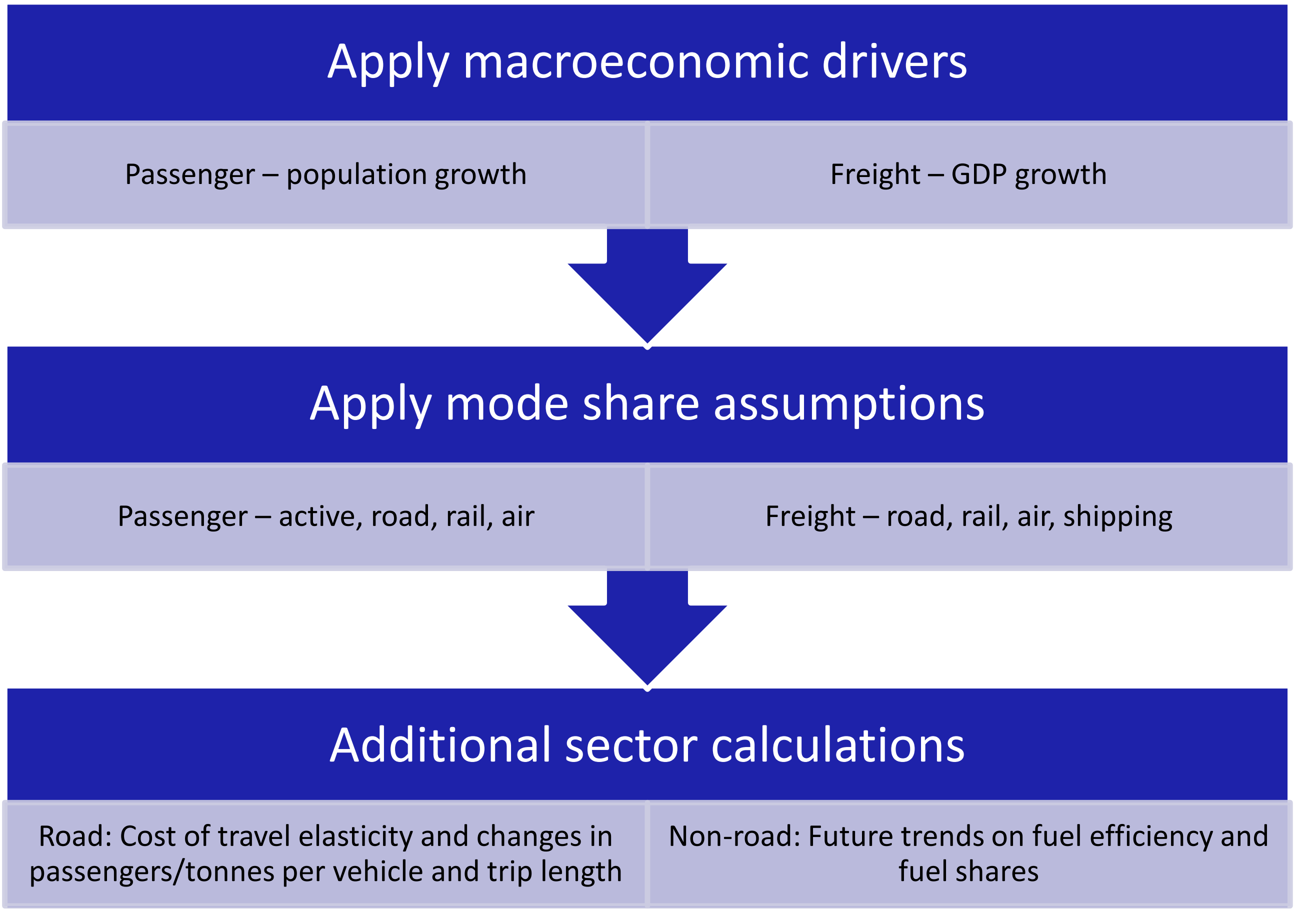
Figure 2-1 Historical and projected electric vehicle sales by state to 2022, Current Trajectory scenario

2.1.2 Transport demand model

An overview of the process of projecting transport demand is shown in Figure 2-2. Growth in passenger (passenger kilometre) and freight (tonne kilometre) transport demand is driven by growth in population and GDP. GDP historically has been the stronger driver of both types of transport, but more recently population has been better at explaining growth in passenger transport. This is because most forms of transport are now affordable under current average household income. That is, the demand for passenger transport per person has reached a saturation point as cost of transport is not a significant barrier. New passenger transport demand is therefore driven by growth in population (immigration assumptions therefore becomes important).

Future mode share assumptions are developed based on an observation of historical trends and consideration of the future of cities in Australia that includes specific government programs to extend airports, rail and road infrastructure. For the non-road sectors, fuel consumption projections are based on multiplying projected demand by long term trends in fuel efficiency. In the past CSIRO would include some changes in mode shares over time . For example, historically, aviation had been steadily capturing more of the passenger share market. However, the COVID-19 pandemic has interrupted and reversed some of these trends. As a conservative approach, the mode shares for passenger transport are mostly held constant at their current levels with only a slight leaning towards previous trends. Freight transport mode shares were less impacted by COVID-19 and so their historical trends in mode share are allowed to continue (Section 4.8 shows the impact of these assumptions).

Figure 2-2: Overview of transport demand model



There are several more steps in projecting road sector transport demand. The first additional step is that the demand model takes cost of travel information from the adoption model and applies a price elasticity to demand of -0.2[2]. That is, if the cost of road transport (passenger or freight) is expected to fall by 10% this will lead to 2% increase in road transport demand. Conversely a 10% increase in cost of travel would lead to a 2% decrease in transport demand. Cost of travel is measured in dollars per kilometre and includes the whole cost of vehicle ownership and operation. The main driver of rising transport costs in the future is expected to be fuel prices. However,

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[2] Transport demand elasticities have been studied for many decades. This site summarises available evidence: https://www.bitre.gov.au/databases/tedb

improved fuel efficiency and higher vehicle utilisation from vehicle electrification and autonomous vehicles respectively could see costs fall.

The second additional step is to take account of changes in the vehicle load. For example, a decrease in passengers per vehicle implies more vehicle kilometres will be required to meet total demand for passenger kilometres. Similarly, an increase in tonnes per vehicle capacity would mean fewer vehicles were required to meet freight tonne kilometre demand. Tonnes per vehicle are held constant over time for freight vehicles. Passengers per vehicle increases if the adoption model projects greater adoption of rideshare services.

The final step takes account of changes in trip length which is measured in aggregate by kilometres per vehicle. Kilometres per vehicle is varied to take account of changes due to the impact of COVID-19 and of autonomous vehicles and ride sharing. COVID-19 has reduced average kilometres per vehicle for passenger vehicles. Alternative assumptions are imposed, depending on the scenario, about how much kilometres per vehicle recovers. In some scenarios, where there is a strong greenhouse gas abatement imperative, it is assumed that kilometres per vehicle remains lower in the longer term to support greater use of telepresence as an abatement measure.

The model projects the uptake of autonomous vehicles and ridesharing and their impact on transport demand. Ride sharing increases the number of passengers per vehicle which on face value reduces the amount of vehicle kilometres needed to meet passenger kilometre demand and this is taken account of in the previous step. However, the most convenient service[3] would pick up and drop off each passenger at their destination meaning that each passenger takes a longer trip than if they had used a non-ride sharing mode. These extra kilometres associated with ride sharing trips are considered in this step.

2.1.3 Consumer technology adoption model

The consumer technology adoption curve is a whole of market scale property that is exploited for the purposes of projecting adoption, particularly in markets for new products. The theory posits that technology adoption will be led by an early adopter group who, despite high payback periods, are driven to invest by other motivations such as values, autonomy and enthusiasm for new technologies. As time passes, fast followers or the early majority take over and this is the most rapid period of adoption. In the latter stages the late majority or late followers may still be holding back due to constraints they may not be able to overcome, nor wish to overcome even if the product is attractively priced. These early concepts were developed by authors such as Rogers (1962) and Bass (1969).

Over the last 50 years, a wide range of applications seeking to use this as a projection tool have experimented with a combination of price and non-price drivers to calibrate the shape of the adoption curve for any given context. Price can be included directly or as a payback period or return on investment. The adoption curve is developed by applying a payback period and a

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[3] Note that the Australian version of UberPool currently does not directly pick up and drop off at your desired points. Rather it includes some walking to connect you with the route an existing vehicle is travelling and may include some walking after drop-off. However, some overseas version include point to point drop-off and pick-up. https://www.uber.com/en-AU/ride/uberpool/

maximum market share assumption. Data on these two inputs are required to calibrate the shape of the logistic curve function.

Payback periods are relatively straightforward to calculate and when compared to price also captures the opportunity cost of staying with the technology substitute. The formula for the payback period, expressed in years, is expressed as follows:

$$PaybackPeriod_{v,m,s,t} = \frac{Capitalcost_{v,m,s,t} - CapitalCostICE_{m,t}}{AnnualOperatingCostICE_{r,m,t} - AnnualOperatingCost_{r,v,m,s,t}}$$

Where:

$$\begin{aligned} AnnualOperatingCost_{r,v,m,s,t} \\ &= AnnualFuelCost_{v,m,s,t} + AnnualMaintenanceCost_{v,m} \\ &+ AnnualRegistrationCost_{r,v,m} + AnnualInsuranceCost_{r,v,m,s,t} \end{aligned}$$

$$\begin{aligned} AnnualOperatingCostICE_{r,m,t} \\ &= AnnualFuelCostICE_{m,t} + AnnualMaintenanceCostICE_{m} \\ &+ AnnualRegistrationCostICE_{r,m} + AnnualInsuranceCostICE_{r,m,t} \end{aligned}$$

r is the region

v is the five electric vehicle type: battery electric (short and long range), plug-in hybrid, fuel cell,

m is the ten road modes or vehicle types: passenger (3 sizes) , light commercial vehicle (3 sizes), rigid truck, articulated truck, bus,

s is the five scenarios,

t is the financial year (to 2051-52).

The *CapitalCost* for internal combustion vehicles (ICE) varies by mode and time. The *CapitalCost* for electric vehicles also varies by the vehicle type and scenario and is net of any subsidies.

The *AnnualFuelCost* for ICE vehicles is calculated as the petroleum price multiplied by average new vehicle fuel efficiency and kilometres travelled per year. The assumptions for these factors change by mode and over time. The *AnnualFuelCost* for electric vehicles is the same formula but varies by vehicle type and scenario to recognise the use of different fuels (electricity and hydrogen) and changes in electricity prices between scenarios.

A more difficult task than calculating the payback period is to identity the set of non-price demographic or other factors that are required to capture other reasons that influences the maximum market share assumption. CSIRO previously investigated the important non-price factors and validated the approach of combining payback periods and non-price factors that provides good locational predictive power for rooftop solar and electric vehicles (Higgins et al 2014; Higgins et al 2012).

In Figure 2-3~~Figure 2-3,~~the general projection approach is highlighted that includes examples of demographics and other factors that are considered for inclusion. An important interim step is also included, which is to calibrate the adoption curve at appropriate spatial scales (due to differing demographic characteristics and electricity prices) and across different customer segments (differences between customers’ travel needs, fleet purchasing behaviour and vehicle utilisation).

Once the adoption curve is calibrated for all the relevant factors, the rate of adoption is evolved over time by altering the inputs according to the outlined scenario assumptions[4]. For example, differences in technology costs and prices between scenarios will alter the payback period and lead to a different position on the adoption curve. Non-price scenario assumptions such as available charging infrastructure or highest educational attainment in a region will result in different adoption curve shapes (particularly the height at saturation or maximum market share). Data on existing market shares determines the starting point on the adoption curve.

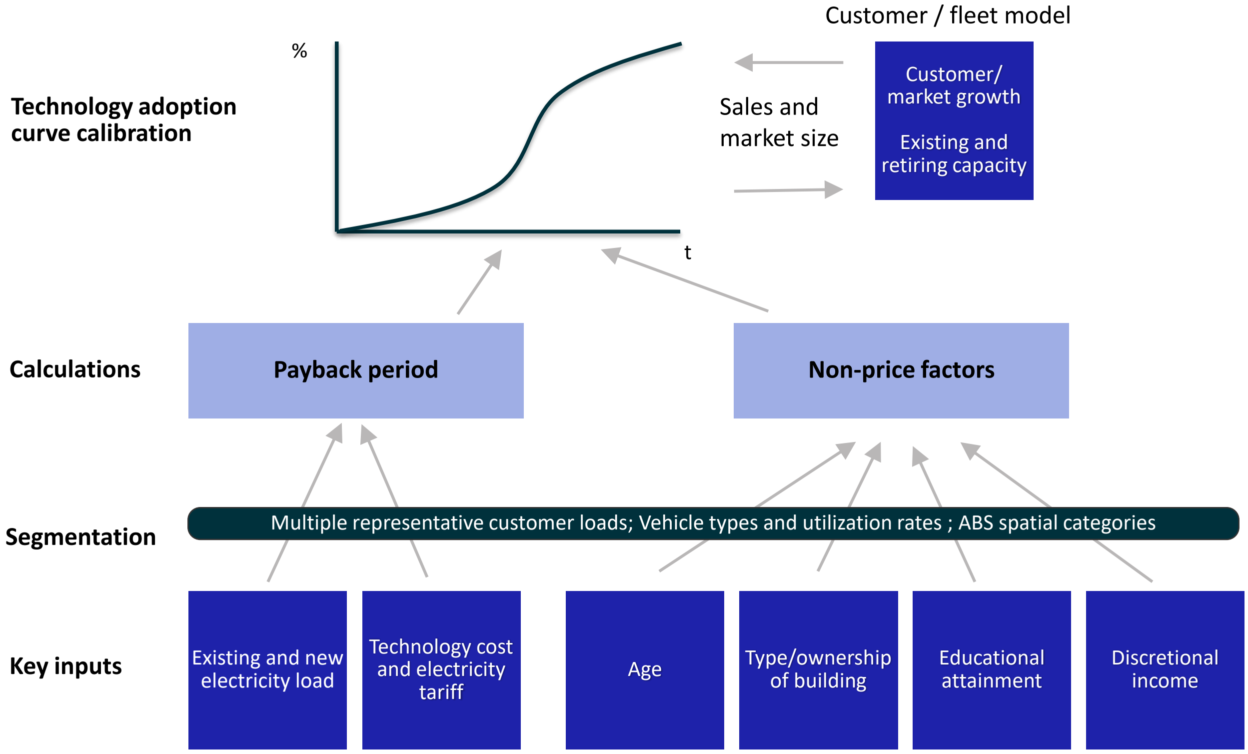

Figure 2-3 Adoption model methodology overview

The methodology also takes account of the total size of the available market and this can differ between scenarios. For example, the total vehicle fleet requirement is relevant for electric vehicles, while the number of customer connections is relevant for rooftop solar and battery storage. The size of these markets is influenced by population growth, economic growth and transport mode trends and this is discussed further in the scenario assumptions section. While a maximum market share is set for the adoption curve based on various non-financial constraints, maximum market share is only reached if the payback period falls. The applied maximum market share assumptions are outlined in the Data Assumptions section.

All calculations are carried out at the Australian Bureau of Statistics Statistical Area Level 2 (SA2) allowing the forecasts to align to the available demographic data. This also allows the conversion of the data back to postcodes for aggregation to the state level as required. The Australian Bureau of Statistics publishes correspondence files which provide conversion factors for moving between

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[4] Note that to "join" the short- and long-term projection models the trends projected to 2021-22 are seen as historical fact from the perspective of the long-term projection model and as such calibrate the adoption curve from that point.

commonly used spatial disaggregation. Each spatial disaggregation can also be associated with a state for aggregation purposes.

2.1.4 Commercial vehicles

It may be argued that commercial vehicle purchasers would be more weighted to making their decisions on financial grounds only. That is, commercial vehicle sales would rapidly accelerate towards electric vehicles as soon as the whole of life cost of owning an EV falls (which also occurs sooner than for residential owners because of the longer average driving distances of commercial vehicles). However, it is assumed that infrastructure constraints including the split incentives or landlord-renter problem which can be captured using adoption curves are also relevant for businesses noting that many commercial vehicles park at residential premises. For business parked vehicles, if the business does not own the building, installing charging infrastructure may not be straight-forward. Hence, the applicability of vehicle range to a business's needs is just as relevant as whether vehicle range will suit a household's needs.

2.2 Demographic factors and weights

The projection methodology includes selecting a set of non-price factors, typically drawn from accessible demographic data to calibrate the consumer technology adoption curve in each SA2 region. CSIRO assigns different weights to each factor to reflect their relative importance. The next section outlines the factors and weights chosen for electric vehicles.

2.2.1 Weights and factors for electric vehicles

Previous analysis by Higgins et al (2012) validated several demographic factors and weights for Victoria. A similar combination of factors and weights is applied and outlined in Table 2-1. These weighting factors provide a guide for the adoption locations, particularly during the early adoption phase which Australia currently remains in. However, adoption is allowed to grow in all locations over time. It is likely that some of the factors included act as a proxy for other drivers not explicitly included (such as income).

The weights and factors are used to calculate a score for each SA2 region to indicate relative propensity for electric vehicle uptake. After a general level of maximum national electric vehicle adoption is set, for example 50%, the SA2 weights and factors are used to score to adjust the local level of adoption up or down by a maximum of plus or minus 25%. In this case the best scoring SA2 region achieves a maximum adoption of 75% and the worst scoring region 25%. The maximum national electric vehicle adoption assumptions are outlined in Section 4 Table 4-4.

Table 2-1 Weights and factors for electric vehicle ownership

Factors	Weight ranges
Share of ages (in 10-year bands)	0-1 with the 35 to 54 age bands receiving highest scores
Share of number of household residents (1-6+)	0.3-1 increasing with smaller households
Share of educational attainment	0.25-1 for advanced diploma and above, 0 otherwise
Share of mode of transport to place of work	1 for car, 0 otherwise

2.3 Role of economic growth in projection method

Economic growth closely tracks changes in residential and business income and the general health of the economy. This provides an overview of how changes in economic growth impact the projections.

Income influences the electric vehicle adoption model only through the size of transport demand. Economic growth is not considered in the demographic score for calibration of the electric vehicle adoption curve. Passenger transport demand is a larger component of transport and this is driven by population growth. However, demand for light commercial vehicle and truck transport is driven by economic growth. This means while stronger demand for EV means more vehicle sales, it influences only a small proportion of growth in vehicle sales. A large proportion of sales is car replacement, this makes up about 80% replacement of vehicle stock.

Changes in economic growth only impacts around 20% of the sales of a minority of vehicle types. As such, alternative economic growth assumptions only has a marginal direct impact on EV projections. Indirectly, if higher economic growth occurred due to higher population growth, that mechanism would broaden the impact of higher economic growth because the whole of transport demand is experiencing higher demand. In that case, the impact would still affect approximately 20% of sales increasing in line with increases in GDP and population.

3 Scenario definitions

The five scenarios are Current Trajectory, Slow Growth, Net Zero, Sustainable Growth and Export Superpower. Rapid Decarbonisation is a sensitivity of Export Superpower. The AEMO scenario definitions are provided as short narratives and settings for key drivers in Table 3-1. For the electric vehicles projections, this section provides an extended scenario definition table based on a deeper consideration of the economic, infrastructure and policy drivers. The section then describes each of the financial and non-financial drivers in more detail.

Current Trajectory scenario

The Current Trajectory scenario reflects a future energy system based around current government policies and best estimates of all key drivers. This scenario represents the current transition of the energy industry under current policy settings and technology trajectories, where the transition from fossil fuels to renewable generation is generally led by market forces. Uptake of DER, energy efficiency measures and the electrification of the transport sector proceeds in line with AEMO's current best estimates. The relevant purpose for this scenario is:

- To provide a basis on which to assess the development of the system under currently funded and/or legislated policies and commitments, using the most probable value/best estimate for each input.

Net Zero scenario

This reflects a world that is like Current Trajectory in the first decade but with a shift in policy towards achieving Net Zero emissions economy wide by 2050.

Sustainable Growth scenario

Higher decarbonisation ambitions are supported by rapidly falling costs for battery storage and variable renewable energy (VRE), which drive consumers' actions and higher levels of electrification of other sectors. Economic and population growth are similar to Current Trajectory. The main differences to Current Trajectory are:

- Economy wide Net Zero emissions by 2050
- Increased cost-competitiveness of VRE and batteries relative to fossil fuel generation.
- DER uptake is driven by consumers seeking to take a greater degree of ownership over their consumption, choosing when and how to consume energy. This is also aided by continued technological advances that extend the strong uptake in DER technologies. Participation in virtual power plant (VPP) aggregation schemes is higher.
- There are high levels of electrification of transport and energy efficiency

The relevant purposes for this scenario are:

- To understand the impact of strong decarbonisation and DER uptake on the needs of the electricity system, and in particular to explore the potential risk of under-investment in the infrastructure required to facilitate this transition.

- To explore the system security impact of high penetration of DER and potential issues and challenges in distribution and transmission networks, and what investments could address these.

Slow Growth scenario

This scenario includes the lowest level of economic growth following the global COVID-19 pandemic, which increases the likelihood of industrial load closures. Decarbonisation at a policy level takes a back seat, but strong uptake of distributed PV continues, particularly in the short-term in response to a number of incentives.

- The rate of technological development and cost reductions stagnates, as falling private investment reduces the speed of cost reductions in technologies such as battery storage.
- In search of cost savings and in response to low interest rates and government incentives to aid the recovery from COVID-19, consumers continue to install distributed PV at high rates, continuing the trends observed during 2020, where uptake has held up and in many regions increased, despite adverse economic conditions. Over time these impacts dissipate and distributed PV uptake moderates.

Key differences to the Current Trajectory scenario include:

- Lower levels of decarbonisation ambitions both internationally and domestically.
- Very low economic activity and population growth.
- Lower levels of electrification.
- Stronger level of DER uptake in the near term

The relevant purposes for this scenario for these consulting services are:

- To assess the risk of over-investment in the power system, in a future where operational demand is much lower, and some less certain policy drivers do not proceed.
- To explore operational and system security risks associated with falling levels of minimum demand

Export Superpower scenario

This scenario represents a world with very high levels of electrification and hydrogen production, fuelled by strong decarbonisation targets and leading to strong economic growth. Key differences to the Current Trajectory scenario include:

- Economy wide Net Zero emission by early 2040s
- The highest level of international decarbonisation ambition, consistent with a target of limiting the global temperature rise to $1.5^{o}C$ by 2100 over pre-industrial levels – this also results in the strongest decarbonisation requirement in the NEM across the scenarios.
- Stronger economic activity and higher population growth.
- Continued improvements in the economics of hydrogen production technologies that enable the development of a large NEM connected hydrogen production industry in Australia for both export and domestic consumption.

- Higher levels of electrification across many sectors, with strong light vehicle electrification but fewer large electric trucks due to competition from hydrogen fuel-cell trucks.

The relevant purpose for this scenario for these consulting services is:

- To understand the implications and needs of the power system under conditions that result in the development of a renewable generation export economy which significantly increases grid consumption and necessitates developments in significant regional renewable energy generation.
- To assess the impact, and potential benefits, of large amounts of flexible electrolyser load.

Rapid Decarbonisation sensitivity

The Rapid Decarbonisation sensitivity has the same scenario settings as Export Superpower but without a large NEM connected hydrogen industry.

Table 3-1 AEMO scenario definitions

Scenario/sensitivity	SLOW GROWTH	CURRENT TRAJECTORY	NET ZERO	SUSTAINABLE GROWTH	RAPID DECARBONISATION	EXPORT SUPERPOWER
Economic growth and population outlook*	Low	Moderate	Moderate	Moderate	High	High
Energy efficiency improvement	Low	Moderate	Moderate	High	High	High
DSP	Low	Moderate	Moderate	High	High	High
Distributed PV (per capita uptake tendency)	Moderate, but elevated in the short term	Moderate	Moderate	High	High	High
Battery storage installed capacity	Low	Moderate	Moderate	High	High	High
Battery storage aggregation / VPP deployment by 2050	Low	Moderate	Moderate	High	High	High
Battery Electric Vehicle (BEV) uptake	Low	Moderate	Moderate	High	High	High*
BEV charging time switch to coordinated dynamic charging by 2030	Low	Moderate	Moderate	High	High	Moderate/High
Electrification of other sectors	Low	Low/Moderate	Moderate	Moderate/High	High	Moderate/High
Hydrogen uptake	Minimal	Minimal	Minimal	Minimal	Minimal	Large NEM-connected export and domestic consumption
Shared Socioeconomic Pathway (SSP)	SSP3	SSP2	SSP2	SSP1	SSP1	SSP1
International Energy Agency (IEA) 2020 World Energy Outlook (WEO) scenario	Delayed Recovery Scenario (DRS)	Stated Policy Scenario (STEPS)	Stated Policy Scenario (STEPS)	Sustainable Development Scenario (SDS)	Net Zero Emissions by 2050 case (NZE2050)	Net Zero Emissions by 2050 case (NZE2050)
Representative Concentration Pathway (RCP) (mean	RCP7.0 (~4°C)	RCP4.5 (~2.6°C)	RCP4.5 (~2.6°C)	RCP2.6 (~1.8°C)	RCP1.9 (<1.5°C)	RCP1.9 (<1.5°C)

Scenario/sensitivity	SLOW GROWTH	CURRENT TRAJECTORY	NET ZERO	SUSTAINABLE GROWTH	RAPID DECARBONISATION	EXPORT SUPERPOWER
temperature rise by 2100)						
Decarbonisation target	26-28% reduction by 2030.	26-28% reduction by 2030.	26-28% reduction by 2030 Economy-wide Net Zero target by 2050.	Consistent with limiting temperature rise to 2 degrees. Economy-wide before 2050	Consistent with limiting temperature rise to 1.5 degrees. Economy-wide Net Zero by early 2040s	Consistent with limiting temperature rise to 1.5 degrees. Economy-wide Net Zero by early 2040s
Generator and storage build costs	CSIRO GenCost Central	CSIRO GenCost Central	CSIRO GenCost Central	CSIRO GenCost High VRE	CSIRO GenCost High VRE	CSIRO GenCost High VRE
Generator retirements	In line with expected closure years, or earlier if economic to do so.	In line with expected closure years, or earlier if economic.	In line with expected closure years, or earlier if economic or driven by decarbonisation objectives beyond 2030.	In line with expected closure year, or earlier if economic or driven by decarbonisation objectives	In line with expected closure year, or earlier if economic or driven by decarbonisation objectives	In line with expected closure year, or earlier if economic or driven by decarbonisation objectives
Relative project finance costs	Lower than Central, reflecting lower rates of return with lower economic growth	In line with current long-term financing costs appropriate for a private enterprise	In line with current long-term financing costs appropriate for a private enterprise	As per Central	As per Central	As per Central

3.1.1 Extended scenario definitions

The AEMO scenario definitions have been extended in Table 3-2 by adding additional detail on the economic, infrastructure and business model drivers. The purpose is to fill out more detail about how the scenarios are implemented whilst remaining consistent with the higher level AEMO scenario definitions. The scenario definitions are in some cases described here in general terms such as “High” or “Low”. More specific scenario data assumptions are outlined further in the next section and in Section 4.

Table 3-2 Extended scenario definitions

Driver	Slow Growth	Current Trajectory	Net Zero	Sustainable Growth	Export Superpower	Rapid Decarbonisation
Economic						
Timing of cost[1] parity of short-range electric vehicles with ICE	2035	2030	2030	2025	2025	2025
Cost of fuel cell vehicles	High	Medium	Medium	Medium	Low	Medium
Infrastructure						
Growth in apartment share of dwellings	High	Medium	Medium	Medium	Low	Low
Decline in home ownership	High	Medium	Medium	Medium	Low	Low
Extent of access to variety of charging options	Low	Medium	Medium High post 2030	High	High	High
Business model						
Feasibility of ride sharing services	Low	Medium	Medium	High	High	High
Affordable public charging availability	Low	Medium	Medium High post 2030	High	High	High
Vehicle to home or grid (passenger vehicles)	Yes from 2030	Yes from 2030	Yes from 2030	Yes from 2030	Yes from 2030	Yes from 2030

1. Upfront sales costs of vehicle, not whole of vehicle running cost. Short range is less than 300km.

3.2 Financial and non-financial scenario drivers

3.2.1 Direct economic drivers

For privately owned electric and fuel cell vehicles the economic drivers and the approach to including them in the scenarios is listed in Table 3-3.

Future hydrogen fuel costs are hard to predict because there is a diversity of possible supply chains, each with their own unique cost structures. While natural gas based hydrogen is currently lowest cost, by the time fuel cell electric vehicles (FCEVs) are relevant, electrolysis hydrogen production is likely to be more competitive and offers the most flexibility for accessing a low carbon energy source and allowing hydrogen to be generated at either the end-user's location, at fuelling stations or at dedicated centralised facilities.

Table 3-3: Economic drivers of electric and fuel cell electric vehicles (FCEV) and approach to including them in scenarios

Driver	Approach to including in scenarios
The whole cost of driving an electric or fuel cell vehicle including vehicle, retail electricity, the charging terminal (wherever it is installed), hydrogen fuel, insurance, registration and maintenance costs	Vehicle costs vary by scenario and are outlined in Section 4.1.1. Retail electricity prices are varied by scenario and outlined in Section 4.2.1. The remaining factors are held constant.
The whole cost of driving an internal combustion engine (ICE) vehicle as an alternative including vehicle, fuel, insurance, registration and maintenance costs	Not varied by scenario
Perceptions of future changes in petroleum-derived fuel costs including global oil price volatility and any fuel excise changes	Not varied by scenario
The structure of retail electricity prices relating to electric vehicle recharging	Varied by scenario and outlined in 4.7
The perceived vehicle resale value	Not varied by scenario

For autonomous private and ride share vehicles the additional economic drivers compared to electric and fuel cell vehicles and the approach to including them in scenarios is shown in Table 3-4.

Table 3-4: Economic drivers of autonomous private and ride share vehicles and approach to including them in scenarios

Driver	Approach to including in scenarios
The cost of the autonomous driving capability	On-cost of autonomous features not varied by scenario but underlying cost of electric vehicle carried by scenario as outlined in Section 4.1.1
The value of avoided driving time	Not varied by scenario but assumptions discussed in Section 4.1.2
The lower cost of travel from higher utilisation of the ride-share vehicle compared to privately owned vehicles (accounting for some increased trip lengths to join up the routes of multiple passengers)	Not varied by scenario
The avoided cost of wages to the transport company for removing drivers from autonomous trucks	Not varied by scenario but assumptions discussed in Section 4.1.2
Higher utilisation and fuel efficiency associated with autonomous trucks	Not varied by scenario

3.2.2 Infrastructure drivers

The are several infrastructure barriers to accessing electric vehicles and associated refuelling (Table 3-5). Electric, fuel cell and autonomous ride share vehicles all face the common constraint of a lack of variety of models in the initial phases of supply of those vehicles. While perhaps ride share vehicles can be more generically designed for people moving, purchasers of privately owned vehicles will prefer access to a wider variety of models to meet their needs for the how they use their car (including sport, sedan, SUV, people moving, compact, medium, large, utility, 4WD, towing).

Table 3-5: Infrastructure drivers for electric and fuel cell vehicles and approach to including them in scenarios

Driver	Approach to including in scenarios
Convenient location for a power point or dedicated charging terminal in the home garage or a frequently used daytime parking area for passenger vehicles and at parking or loading areas for business vehicles such as light commercial vehicles, trucks and buses	Varied by scenario and expressed as maximum market share in Section 4.5
Whether the residence or business has ownership or other extended tenancy of the building or site and intention to stay at that location to get a long-term payoff from the upfront costs of installing the charger.	Varied by scenario and expressed as maximum market share in Section 4.5
Convenient access to highway recharging for owners without access to extended range capability (or other options, see below)	Varied by scenario and expressed as maximum market share in Section 4.5
Access to different engine configurations of electric vehicles (e.g. fully electric short range, fully electric long range and plug-in hybrid electric and internal combustion)	Varied by scenario and expressed as maximum market share in Section 4.5
Convenient access to other means of transport such as a second car in the household, ride sharing, train station, airport and hire vehicles for longer range journeys	Varied by scenario and expressed as maximum market share in Section 4.5
Whether hydrogen distribution and refuelling terminals have been deployed widely enough for convenient use of fuel cell vehicles	Varied by scenario and expressed as maximum market share in Section 4.5

Key infrastructure drivers for FCEVs are varied by scenario as maximum market share assumptions and outlined in Section 4.5. The drivers are:

- A mature hydrogen production and distribution supply chain for FCEVs. There are many possible production technologies and resources and many ways hydrogen can be distributed with scale being a strong determinant of the most efficient distribution pathway (e.g. trucks at low volumes, pipelines at high volumes).
- The greater availability of FCEVs for sale.

Sufficient electricity distribution network capacity to meet coincident charging requirements of high electric vehicle share could also be an infrastructure constraint if not well planned for. However, networks are obligated to expand capacity or secure demand management services to meet load where needed and so any such constraints would only be temporary. If hydrogen supply is based on electrolysis this will also mean increased requirements for electricity infrastructure, but its location depends on whether the electrolysis is on site (e.g. at a service station) or centralised (where the location might be a prospective renewable energy zone or fossil fuel resource).

Given the constraints of commute times and cost of land in large cities, there is a slow trend towards apartments rather than separate dwellings in the capital and large cities where most Australians live. This is expected to result in a lower share of customers with access to their own roof or garage space impacting all types of embedded generation (these assumptions are defined later in the report). There has also been recent evidence of a fall in home ownership, especially amongst younger age groups. For electric vehicles these trends might also work towards lower adoption as denser cities tend to encourage greater uptake of non-passenger car transport options and ride sharing services (discussed further in the next section) which result in fewer vehicles sold. Home ownership and separate dwelling share are varied by scenario and outlined in Section 4.4

3.2.3 Disruptive business model drivers

New business models can disrupt economic and infrastructure constraints by changing the conditions under which a customer might consider adopting a technology. Table 3-6 explores some emerging and potential business models which could drive higher adoption. Demand management is an example where trials and rule changes which are the basis of emerging business models could become more established in the long run. The degree to which these potential business model developments apply by scenario is expressed primarily through their ability to change the maximum market shares for electric, autonomous and fuel cell vehicles as outlined in Sections 4.5 and 4.8.1.

Table 3-6 Emerging or potential disruptive business models to support embedded technology adoption

Name	Description	Constraint reduction reasoning
Affordable public charging	Ubiquitous public charging is provided cost effectively	Low cost access to electric vehicle charging will be primarily at the home or business owner’s premises
Charging into the solar production period	Businesses offer daytime parking with low cost-controlled charging and provide voltage control services to the network in high solar uptake areas	Electric vehicle charging will be primarily at home and overnight, poorly matched with solar

Autonomous ride-share vehicles[1]	Ride sharing services which utilise autonomous vehicles could result in business-led electric vehicle uptake achieving very high vehicle utilisation and lower whole of life transport costs per kilometre	Electric vehicles will be predominantly used for private purposes by the vehicle owner and the return on their investment will be governed by that user's travel patterns.
Vehicle to home or grid	Electric vehicles are coupled with an in-garage inverter system to provide the role of a stationary battery when at home. This aligns well with public charging during high solar generation periods or other system needs.	Using the battery capacity in your electric vehicle for home or system energy management may require a more complicated setup and may impact on the amenity of vehicle operation for transport purposes
Hydrogen economy	Australia becomes a major hydrogen exporter and this supports some economies of scale in domestic supply of electrolysis-based hydrogen for fuel cell vehicles as well as providing a large source of electricity demand management	Hydrogen distribution, transmission and storage infrastructure is not established and will involve high upfront costs. Electricity system requires large amount of investment in storage and demand management to balance variable renewable generation
Collapse of internal combustion engine (ICE) business model	Sales of ICE vehicles fall to a level such that ICE oriented businesses (petroleum fuel supply, vehicle maintenance) lose economies of scale	A "laggard" group of customers choose to continue to preference ICE vehicles so long as they are only marginally higher cost to own than electric or fuel cell vehicles.

1 While increasing the kilometres travelled via electric vehicles, this may potentially reduce the number of electric vehicles overall since this business model involves fewer cars but with each car delivering more kilometres per vehicle.

3.2.4 Commonwealth policy drivers

There are a variety of commonwealth policy drivers which impact solar, battery and electric vehicle adoption. These are rationalised for each scenario and described in further detail below.

Emissions Reduction Fund[5] and Climate Solutions Fund

The ERF consists of several methods for emission reduction under which projects may be eligible to claim emission reduction and bid for Australian Carbon Credit Units (ACCUs) which are currently awarded via auction at around \$15/tCO_2e. The relevant method in this case is the *Carbon Credits (Carbon Farming Initiative – Land and Sea Transport) Methodology Determination 2015*. It is possible for businesses to develop projects under the ERF where each project may receive funding for deployment of electric vehicles. However, there have been no significant uptake of this scheme as the incentive is not significant. Although it is expected for the ACCU price to increase over time, it currently provides an incentive of only \$15/tCO2e. ICE passenger vehicle emissions is around 4 tonnes per year and this is only estimated to be roughly \$60 per year in benefits.

Potential changes to Commonwealth renewable energy and climate policy

While there are currently no announced changes to renewable energy and climate policy, given Australia's nationally determined commitment at the Paris UNFCCC meeting, it is likely there may be adjustments to those policies in the future. The Export Superpower and Sustainable Growth scenarios imply the deployment of such additional policies. Given the low cost of greenhouse gas emissions as a share of the overall cost of transport, it is more likely that a non-price mechanism will be deployed in the transport sector to achieve emission reduction.

Australia is one of the few developed countries internationally without vehicle greenhouse gas emissions or fuel economy standards. Consequently, vehicles sold in Australia are around 20% less efficient than the same model sold in the UK (CCA 2014). Low emission vehicles such as electric vehicles are expected to be adopted with or without emission standards, but new policies could accelerate their adoption to ensure any Net Zero emission targets are met in a timely manner (without the delay imposed by stock turnover rates). In addition, there is also currently no Commonwealth fuel excise on electricity or hydrogen used in transport. Some states have begun considering or introducing kilometre based electric vehicle charges. As such, CSIRO has included state based road user charges into the modelling that is outlined in the next section.

3.2.5 State policy drivers

South Australia and Victoria have both announced new road user chargers for electric vehicles which are otherwise exempt from fuel excise[6]. Other states may also be considering introducing similar policies[7]. The rate of the road user charge is yet to be determined in South Australia but for Victoria, it is 2.5 cents/km. The average driving kilometres of approximately 11,000 km/year would represent an annual charge of \$275.

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[5] The Emissions Reduction Fund (ERF) was extended by the Climate Solutions Fund announced in 2019

[6] While policy announcements raise this point, it is not clear how one substitutes for the other in practice when fuel excise is collected by the commonwealth and road user charges are proposed to be collected by states.

[7] It has been reported that the Board of Treasurers commissioned research on how to introduce road user charges: Australian states were warned road user tax on electric vehicles could discourage uptake | Electric, hybrid and low-emission cars | The Guardian

South Australia has an $18 million EV action plan[8] which includes building a fast charging network and purchase of electric vehicles for its government fleet. This has strong similarities to Western Australia[9] which has committed $21 million to creating a fast charging network covering from Perth to Esperance in the south, Kalgoorlie in the east and Kununurra in the north. It will also acquire 25 electric vehicles for the state government fleet.

Victoria provides a $100 discount on annual registration fees for electric vehicles[10]. This represents an ongoing subsidy of electric vehicles relative to other vehicle types. Other states offer similar policies including stamp duty discounts. The Victorian government has also announced a target of 50% of light vehicle sales to be zero emission vehicles (i.e. including both battery and fuel cell electric vehicles)[11]. The target is supported by subsidies for 20,000 vehicles available from July 2021. The first 4,000 vehicles will receive a subsidy of $3,000 with the amount of subsidy for the remainder yet to be determined. Due to the timing of this policy announcement, this has not been included in the modelling and may accelerate adoption of both battery and fuel cell electric vehicles in Victoria.

The Australian Capital Territory's policy[12] offers a substantial package of financial incentives. Interest free loans of up to $15,000 are available as well as stamp duty and registration exemptions. Average environmental performance vehicles at or below $45,000 are normally subject to 3% stamp duty. A 5% stamp duty is applicable for each dollar above $45,000. Electric vehicles registered for the first time are exempt from this stamp duty. This application of different stamp duty rates to new vehicles is an approach unique to the Australian Capital Territory. It amounts to an upfront subsidy of $1350 on a $45,000 electric vehicle or $2110 on a $60,000 electric vehicle. Electric vehicles receive 2 years of free vehicle registration.

Given these policy developments at the Commonwealth and state level, the policies applied are outlined in Table 3-7 and assigned to each scenario.

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[8] State Government's Electric Vehicle Action Plan | LGA South Australia

[9] Electric Vehicle Strategy | Western Australian Government (www.wa.gov.au)

[10] Hybrid or electric vehicle registration discounts : VicRoads

[11] Zero Emissions Vehicle (ZEV) Subsidy | Solar Victoria

[12] Zero Emissions Vehicles - Environment, Planning and Sustainable Development Directorate - Environment (act.gov.au)

Table 3-7 Electric vehicle policy settings by scenario

	Slow Growth	Current Trajectory	Net Zero	Sustainable Growth	Export Superpower	Rapid Decarbonisation
ICE vehicle availability	New ICE vehicles unavailable beyond 2070	New ICE vehicles unavailable beyond 2060	New vehicles unavailable beyond 2050	New vehicles unavailable beyond 2040	New vehicles unavailable beyond 2035	New vehicles unavailable beyond 2035
ICE retirement	Natural retirement	Natural retirement	Deregistered from 2055	Deregistered from 2050	Deregistered from 2045	Deregistered from 2045
Road user charges	2.5c/km from 2022	2.5c/km from 2025	2.5c/km from 2025	2.5c/km from 2030	2.5c/km from 2035	2.5c/km from 2035
Subsidies (stamp duty, registration exemptions or direct financing)	Current policies retained until 2025	Current policies retained until 2030	Current policies retained until 2030	Current policies retained until 2030	Current policies retained until 2030	Current policies retained until 2030

4 Data assumptions

This section outlines the key data assumptions applied to implement the scenarios. Some additional data assumptions which are used in all scenarios are described in Appendix A.

4.1 Technology costs

4.1.1 Electric and fuel cell vehicles

Current Trajectory scenario short-range electric vehicle (SREV) costs are assumed to reach upfront cost of vehicle parity with internal combustion engine light vehicles in 2030 and remain at that level thereafter (Table 4-1). Heavy SREVs are assumed to reach up front cost parity in 2040 due to their delayed development relative to light vehicles and higher duty requirements (both load and distance). Up front cost parity may be reached earlier in other countries where vehicle emissions standards are expected to increase the cost of internal combustion vehicles over time. The modelling considers SREV adoption across five vehicle classes: light, medium and large cars, rigid trucks and buses. Long-range electric vehicles (LREVs) also include larger articulated trucks which perform the bulk of long-distance road freight. LREVs do not reach up front vehicle cost parity because their extra range adds around $5,000 in battery costs to light vehicles (and proportionally more to heavy vehicles). However, from a total cost of driving perspective (i.e. $/km), LREVs are below cost parity by 2030, paying back the additional upfront cost through fuel savings within 2-3 years.

The modelling does not consider applying a plug-in hybrid engine configuration to the small light vehicle class as these vehicles are already efficient so the additional cost would be difficult to payback with limited additional fuel savings.

The Slow Growth, Net Zero, Export Superpower, Sustainable Growth and Rapid Decarbonisation assumptions are framed relative to these Current Trajectory scenario assumptions. The Net Zero cost trajectories are the same as Current Trajectory. In the Slow Growth scenario, it is assumed that the cost reductions are delayed by 5 years to 2035. In the Export Superpower, Rapid Decarbonisation and Sustainable Growth scenarios it is assumed the cost reductions are brought forward by 5 years to 2025.

Given that fuel cell and electric vehicles have significantly fewer parts than internal combustion engines it could also have been reasonable to consider their costs reaching lower than parity with internal combustion vehicles. However, in the context of the adoption projection methodology applied here, when the upfront price of an electric vehicle equals the upfront price of an equivalent internal combustion vehicle, the payback period is already zero in the sense that there is no additional upfront cost to recover through fuel savings. After this point, adoption is largely driven by non-financial considerations. Also, it was considered that vehicle manufacturers might continue to offer other value-adding features to the vehicle if this point is reached rather than continue reducing vehicle prices (e.g. luxury, information technology and sport features).

Table 4-1 Current Trajectory scenario internal combustion and electric vehicle cost assumptions, 2020 $’000

	2020	2025	2030	2035	2040	2045	2050
Internal combustion engine							
Light/small car - petrol	15	15	15	15	15	15	15
Medium car - petrol	25	25	25	25	25	25	25
Large/heavy car - petrol	41	41	41	41	41	41	41
Rigid trick - diesel	61	61	61	61	61	61	61
Articulated truck - diesel	300	300	300	300	300	300	300
Bus - diesel	180	180	180	180	180	180	180
Electric vehicle short range							
Light/small	27	21	15	15	15	15	15
Medium	47	36	25	25	25	25	25
Large/heavy	65	53	41	41	41	41	41
Rigid truck	104	92	80	70	61	61	61
Bus	269	246	223	200	180	180	180
Electric vehicle long range							
Light/small	39	28	20	20	20	20	20
Medium	59	42	30	30	30	30	30
Large/heavy	80	61	46	46	46	46	46
Rigid truck	143	125	109	95	83	82	81
Articulated truck	901	694	535	468	410	404	400
Bus	310	279	252	227	204	203	202
Plug-in hybrid electric vehicle							
Medium car - petrol	37	35	33	33	33	33	33
Large/heavy car- petrol	58	53	49	49	49	49	49
Rigid truck – diesel	N.A.	122	81	81	81	81	81
Articulated truck - diesel	N.A.	606	396	396	396	396	396
Fuel cell vehicle							
Light/small	45	35	32	27	24	22	22
Medium	50	41	37	33	30	29	28
Large/heavy	62	51	48	43	40	38	37
Rigid truck	112	96	84	77	71	70	68
Articulated truck	558	479	419	385	357	350	342
Bus	242	221	207	199	192	190	188

4.1.2 Autonomous vehicle costs and value

Autonomous vehicles (AVs) could have benefits for all vehicle classes from cars through to buses and freight trucks. Published costs are mostly focussed on cars and CSIRO scales these up for other vehicle types by applying the same premium. BCG (2015) conducted expert and consumer interviews establishing that an autonomous vehicle (AV) would have a premium of around $15,000 and that customers would be willing to pay a premium of around $5000 to own a fully autonomous road passenger vehicle. This last point seems to align well with the concept of valuing people's time saved in transport studies. If commuting via an autonomous vehicle gives back 1 hour of time for other activities per working day and if that time is valued that at around $20/hr (slightly more than average earnings), then its value over 235 working days (assuming 5 weeks leave) is $4700 per year.

KPMG (2018) uses a value of 20% for the AV cost premium which would be $3,000 to $8,200 for the standard passenger vehicle types used in our modelling. CSIRO interprets this costing approach as a focus on a larger vehicle and longer-term point of view (i.e. not a first of a kind vehicle). This matches the expectation that the autonomous vehicles would initially be targeted towards the larger less-budget conscious end of the market.

Based on these studies, CSIRO assumes AVs commands a premium starting at $10,000 in 2020 decreasing to $7,500 by 2030 and remaining at that level. Given how consumers value time, significant cost reductions beyond these assumptions are not be necessary to support growth in adoption. However, it is assumed that the vehicles will not be available for adoption until the late 2020s.

For freight vehicles, the major value from AVs are fuel consumption savings through platooning, resting drivers so they can complete longer trips without a break or, if technically feasible, completely removing the driver.

By removing the driver, the wages costs are avoided which are on average around $75,000 per annum while also increasing truck utilisation. Our assumption is that AV truck premiums will be significantly higher (proportionate to the ratio of truck to passenger car costs) owing to the greater complications of a larger vehicle under load in terms of reaction times for autonomous systems and the requirement of better sensing for AVs. However, if these vehicles can achieve full autonomy, the financial incentives are significant.

These assumptions set the economic foundations for AVs which is an important driver for adoption. The adoption of AVs, particularly those with ride share capability in the passenger segment, results in changes to the required size of vehicle fleet and sales which has secondary impacts on the adoption of all vehicles. These issues are discussed further in Section 4.8.1.

4.2 Electricity tariffs

4.2.1 Assumed trends in retail prices

Retail prices are stable throughout the projection period and are not a strong driver of uptake trends or differences between scenarios. This is because electricity refuelling costs are a small proportion of total vehicle running costs (the vehicle is the main cost). Modest differences between a small component across scenarios therefore cannot drive major changes in vehicle adoption.

Broadly speaking retail electricity generation prices are expected to ease in the short term reflecting a relaxed electricity supply-demand balance. Some modest increases are assumed later in the projection period as higher electricity generation prices are required to support investment necessary for replacement of retiring generation capacity and to meet new demand growth. The non-generation components of the retail price are expected to be more stable.

Retail electricity prices in Western Australia and Northern Territory are set by government and are therefore less volatile. Commercial retail prices are assumed to follow residential retail price trends for all scenarios, although under different tariff structures.

4.2.2 Current electricity tariff status

Electricity tariff structures are important in determining the return on investment from customer adoption of EVs and, perhaps importantly for the electricity system, how they operate those technologies. The vast majority of residential and some small-scale business customers have what is called a ‘flat’ tariff structure which consists of a daily charge of $0.80 to $1.20 per day and a fee of approximately 20 to 30c for each kWh of electricity consumed regardless of the time of day or season of the year. Customers with rooftop solar will have an additional element which is the feed-in tariff rate for solar exports. Customers in some states have an additional discounted ‘controlled load’ rate which is typically connected to hot water systems.

Except where flat tariffs are available to smaller businesses, in general, business customers generally face one of two tariff structures: ‘time-of-use’ (TOU) or ‘demand’ tariffs. In addition to a daily charge, TOU tariffs specify different per kWh rates for different times of day. Demand tariffs impose a capacity charge in $/kW per day in addition to kWh rates (with the kWh rates usually discounted relative to other tariff structures). Demand tariffs are more common for larger businesses. TOU and demand tariffs may also be combined. Both types of business tariff structures reflect the fact that, at a wholesale level, the time at which electricity is consumed and at what capacity does affect the cost of supply. These tariff structures are not perfectly aligned with daily wholesale market price fluctuations but are a far better approximation than a flat tariff. In that sense, TOU and demand tariffs are also described as being more ‘cost reflective’ or ‘smart’ tariffs.

4.2.3 Future developments in DER incentives and management

While retailers make business-like TOU and demand tariff structures available to residential customers in addition to flat tariffs, their adoption is low (0 to 20% depending on the state). For both efficiency and equity purposes, both regulators (e.g. AEMC, 2012) and the electricity supply chain (e.g. CSIRO and ENA, 2017) would prefer to see greater residential adoption of the more cost reflective TOU and demand tariffs.

The AEMC has had some success in changing network tariffs charged to retailers to include more TOU and demand elements. Also, some battery and electric vehicle owners currently engage a third party (such as an energy service company or retailer) to control their devices to reduce electricity costs (e.g. optimising battery charging or discharging against a TOU tariff or including electric vehicles in controlled device tariffs usually applied to hot water systems). CSIRO’s calculations show shifting from a flat tariff to a TOU tariff saves around 7% on a customer’s bill with an uncertainty range around that depending on the tariff structure located in your network zone. Customers are not given any guarantee that current TOU pricing structures or levels will continue.

There are no current policies which would substantially increase residential customer adoption of alternative tariff structures. As such, given the self-evident lack of uptake of available alternatives, the prospects for greater residential adoption are considered low[13]. However, customers may indirectly participate in TOU pricing by using public charging infrastructure (daytime charging) which is subject to a TOU tariff between the business and retailer. The assumptions for the share of vehicles adopting such charging practices are outlined in Section 4.5. Night charging does allow for some adoption of TOU pricing at home. This is also the more common practice for business vehicles. Residential home convenience charging (which features charging through the peak) assumes those customers remain on a flat tariff and these are generally in the majority.

CSIRO also considers more direct control measures. Direct control measures in the context of electric vehicles are called vehicle to home or vehicle to grid schemes and only recently began trialling in Australia.

This report does not outline the operation of vehicles under this scheme – this is estimated by AEMO in their market modelling. CSIRO only estimates the number of vehicles participating in such schemes on a static basis. CSIRO includes vehicle to home and vehicle to grid from 2030 in all scenarios. It is strongest, however, in the Export Superpower scenario where it is assumed that the share of participating vehicles grows to 35% by 2050. It is assumed those participating in such schemes can access lower cost charging similar to off-peak pricing in a TOU tariff.

4.3 Income and population growth

4.3.1 Gross state product

Gross state product (GSP) assumptions by scenario are presented in Table 4-2 and these are provided by AEMO and their economic consultant, BIS Oxford Economics. These assumptions have been applied to project commercial and freight vehicle numbers and are relevant for calibrating adoption functions where income is part of the adoption readiness score. However, in our projection methodology, movement along the adoption curve is largely driven by factors other than economic growth. As such, economic growth assumptions have only a marginal impact (no more than 20%) on projections (for more discussion see Section 2.3).

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[13] Stenner et al (2015) provide further insights on customer's responses to alternative tariffs.

Table 4-2 Average annual percentage growth in GSP to 2050 by state and scenario, source: AEMO and economic consultant

Scenario	New South Wales	Victoria	Queensland	South Australia	Western Australia	Tasmania	Australian Capital Territory
Slow Growth	1.6	2.0	1.8	1.4	2.1	1.3	2.0
Current Trajectory	2.0	2.3	2.1	1.7	2.4	1.6	2.3
Net zero	2.0	2.3	2.1	1.7	2.4	1.6	2.3
Sustainable Growth	2.0	2.3	2.2	1.8	2.6	1.7	2.3
Export Superpower	2.5	3.0	2.6	2.2	2.8	1.9	2.6
Rapid Decarbonisation	2.5	3.0	2.6	2.2	2.8	1.9	2.6

4.3.2 Population

Population growth assumptions by scenario are shown in Table 4-3. These assumptions have been applied for determining growth in passenger transport demand.

Table 4-3 Average annual percentage rate of growth in customers to 2050 by state and scenario (Pre-COVID-19), source: AEMO and economic consultant

Scenario	New South Wales	Victoria	Queensland	South Australia	Western Australia	Tasmania	Australian Capital Territory
Slow Growth	0.7	1.1	1.1	0.4	1.1	0.1	1.0
Current Trajectory	0.9	1.3	1.3	0.6	1.4	0.2	1.2
Net zero	0.9	1.3	1.3	0.6	1.4	0.2	1.2
Sustainable Growth	0.9	1.3	1.3	0.6	1.4	0.2	1.2
Export Superpower	1.2	1.6	1.6	0.9	1.7	0.4	1.4
Rapid Decarbonisation	1.2	1.6	1.6	0.9	1.7	0.4	1.4

4.4 Separate dwellings and home ownership

4.4.1 Separate dwellings

Owing to rising land costs in large cities where most residential customers reside, there is a trend towards building of apartments that are stratas, compared to detached houses (also referred to as separate dwellings in housing statistics). As a result, it is expected that the share of separate dwellings will fall over time in all scenarios (Figure 4-1). This assumption does not preclude periods of volatility in the housing market where there may be over and undersupply of apartments relative to demand. The assumptions for the Current Trajectory, Net Zero and Sustainable Growth scenario were built by extrapolating past trends resulting in separate dwellings occupying a share of just below 60% by 2050, around 6 percentage points lower than the 2016 ABS Census data. The Slow Growth, Export Superpower and Rapid Decarbonisation assumptions were developed around that most likely projection with the latter two scenarios experiencing a less rapid shift to apartments which supports higher electric vehicle adoption.

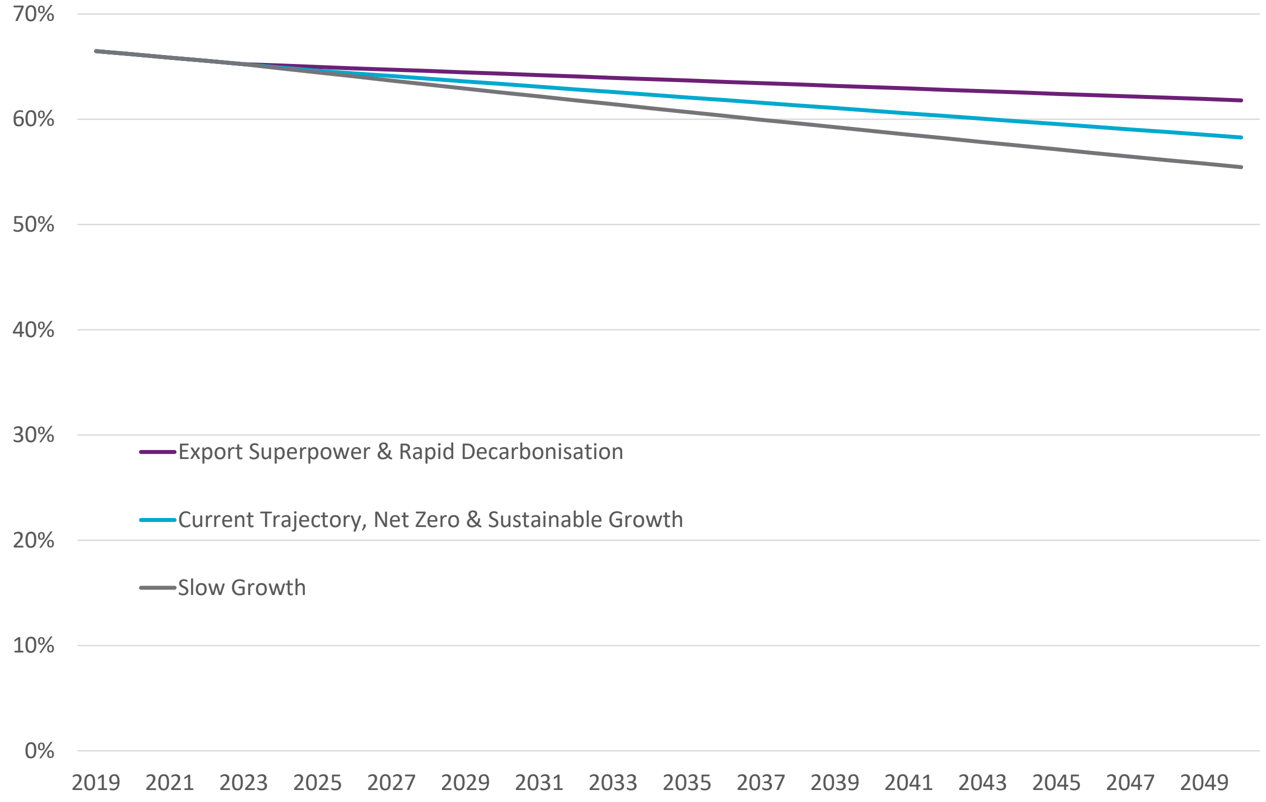

Figure 4-1 Assumed share of separate dwellings in total dwelling stock by scenario

4.4.2 Home ownership

While not a hard constraint, home ownership increases the ability of occupants to modify their house to include small-scale embedded technologies and EV chargers. Home ownership (which includes homes owned outright and mortgaged) increased rapidly post-World War II and was steady at around 70% for the last century. However, in the last 15 years ABS Census data reports (up to 2016) by AIHW (2017) shows that home ownership has been declining and averaged 65.5% in 2016. The largest decline of ownership is among young people (25 to 34). In fact, all ages below 65 experienced a consistent decline in Censuses since 2001.

Over the long run, it is expected that the housing market will respond by providing more affordable home ownership opportunities. However, it is acknowledged that the last 15 years represents a persistent declining trend (Figure 4-2). As such, under the Current Trajectory, Net Zero and Sustainable Growth scenarios, CSIRO assumes the trend of home ownership continues to wane and applies a similar rate of decline in the last 15 years up to 2050 for our forecasts. For the Slow Growth scenario, CSIRO assumes a faster declining trend consistent with that of the last 5 years, leading to a slightly faster reduction in home ownership rates. While for the Export

Superpower and Rapid Decarbonisation scenarios, consistent with higher DER adoption, CSIRO assumes a slower rate of decline in home ownership consistent by applying the trend of the last 25 years representing a slowing in the rate of decline relative to recent history (Figure 4-2).

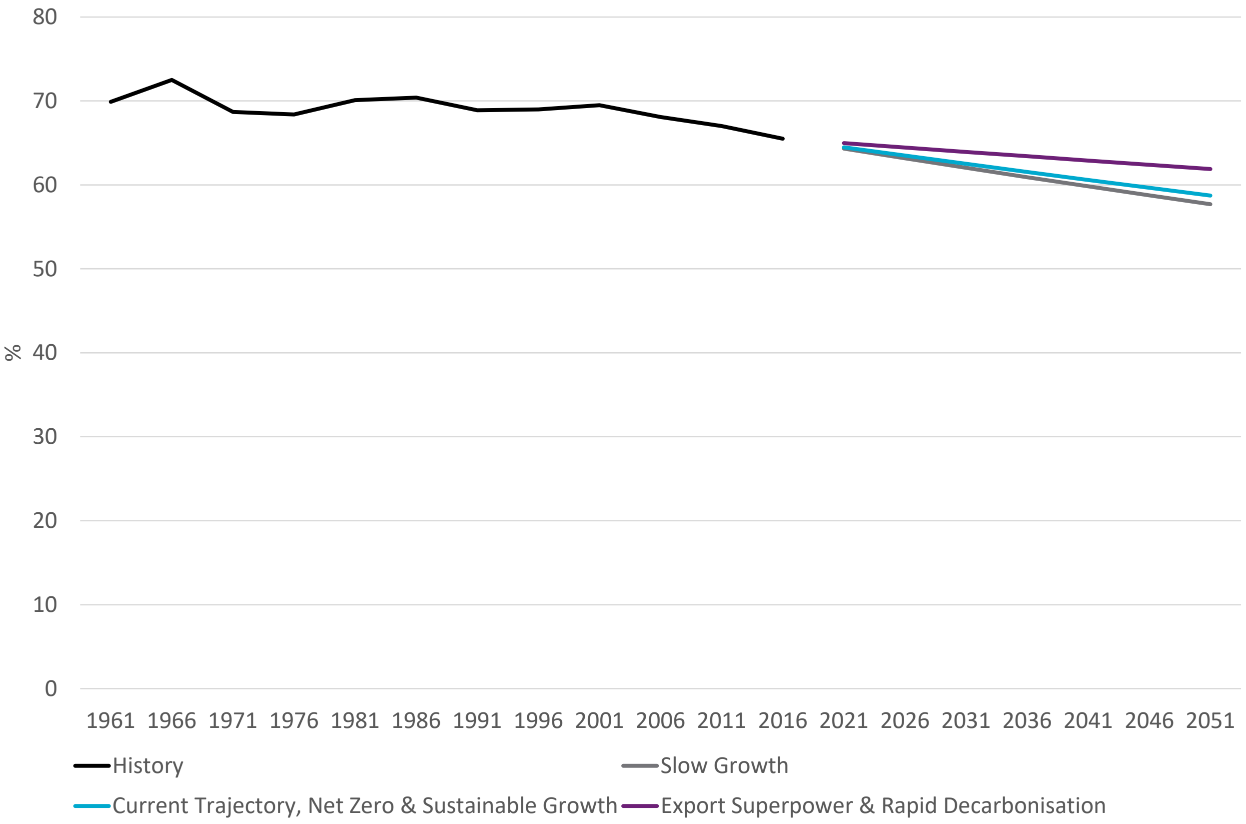

Figure 4-2 Historical (ABS Census) and projected share of homes owned outright or mortgaged, source AIHW (2017)

4.5 Vehicle market segmentation

It is useful to segment the market for electric and fuel cell vehicles to determine if any constraints should be applied to the maximum market share in the adoption projections. This also allows the assignment of different shares of electric vehicle charging profiles to different segments to understand the diversity of charge behaviour across the fleet.

In Table 4-4 below, CSIRO lists non-financial factors that might limit the size of a vehicle in each market segment. These are generally based around limits faced by households because the relevant data for households is more readily available. CSIRO suggests that many of the applied limitations apply equally to businesses such that there is an equivalent concept (see the last column). Each row describes the share of households in each scenario to which the factor applies and the rationale for that assumption which may be a combination of data sources and scenario assumptions.

The table concludes by calculating the maximum market share for each vehicle category via the formulas shown. The maximum market shares are then applied to calibrate the consumer technology adoption curve. The calibration works in a way such that the maximum market share of sales is allowed if the payback period has fallen to a very low level (e.g. one year). At higher payback periods, sales are less than the maximum market share. An exception is Net Zero, Sustainable Growth, Export Superpower and Rapid Decarbonisation where, by design, the electric and fuel cell vehicle adoption rate is set to achieve 100% of the fleet for cars, buses and rigid (smaller) truck by 2055, 2050, 2045 and 2045 respectively.. This complete transformation of the vehicle fleet to zero emission vehicles is consistent with the scenario narrative of net zero greenhouse gas emissions in those scenarios.

In most cases, the market shares across vehicle types adds up to greater than 100%. As such they should be interpreted as the maximum achievable share to be reached independent of competition between vehicles. When applied in the model, the after-competition share is lower. Note that autonomous ride share vehicles are assumed to be a subset of long-range electric vehicles since this is the most natural vehicle type for this service (i.e. lowest fuel cost for high kilometre per year activity). The market share limits are imposed on average. However, the modelling allows individual locations (modelled at the ABS statistical area level 2) to vary significantly from the average according to their demographic characteristics).

Table 4-4 Non-financial limitations on electric and fuel cell vehicle uptake and the calculated maximum market share

		Current Trajectory	Slow Growth	Net zero	Sustainable Growth	Rapid Decarbonisation	Export Superpower	Rationale/formula	Equivalent business constraint
Limiting factors (residential)									
Separate dwelling share of households	A	58%	55%	58%	62%	62%	62%	Based on housing industry forecasts	Businesses located on standalone site
Share of homeowners	B	59%	58%	59%	62%	62%	62%	Based on historical trends	Business not renting their site
Share of landlords who enable (passively or actively) EV charging onsite	C	70%	60%	70%	90%	100%	100%	Data not available. Assumed range of 20-80%	Same
Off-street parking/private charging availability	D	41%	37%	44%	48%	49%	49%	Assume 80% of separate dwellings have off-street parking. Formula=(0.8*A*B)+(0.8*A*(1-B)*C)	Same
Public or multi-occupant building charging availability	E	30%	25%	40%	60%	70%	70%	Availability here means at your work/regular daytime parking area, apartment carpark or in your street outside your house. Assumptions are based on this type of charging being the least financially viable.	Same
Share of houses that have two or more vehicles	F	60%	58%	60%	65%	75%	75%	Based on historical trends	Share of businesses with two or more fleet vehicles
Share of houses where second vehicle is available for longer range trips	G	70%	67%	70%	75%	80%	80%	Assumed range of 65-75%. There may be a range of reasons why second vehicle is not reliably available for longer trips	Operational availability of fleet vehicles
Share of people who would prefer ICE regardless of EV/FCEV costs or features	H	20%	25%	20%	0%	0%	0%	Based on laggards generally being no larger than a third of customers. Sustainable growth assumes ICEs suffer a collapse in manufacturing due to systematic loss of supporting infrastructure	Business owner's attitudes and specific vehicle needs

		Current Trajectory	Slow Growth	Net zero	Sustainable Growth	Rapid Decarbonisation	Export Superpower	Rationale/formula	Equivalent business constraint
Share of people who prefer private vehicle ownership for all household cars	I	90%	95%	90%	85%	85%	85%	General preference for private vehicle ownership	Business preference for private ownership
Share of people willing for their second or more cars to be replaced with ride share	J	10%	5%	10%	15%	20%	20%	Assumed that only a laggard proportion would object to this arrangement	Same
Fuel stations with access to hydrogen supply chain	K	10%	5%	10%	10%	10%	30%	Data not available due to uncertainty. Assume range of 5-30%.	Same
Maximum market share									
Short range electric vehicles		15%	12%	16%	25%	31%	31%	Limitations are limited range and charging. Due to range issue, assume SREVS only purchased by two or more car households and 10% of 1 car households. Formula=[(F*G*D)+(0.1*(1-F)*D)]*(1-H)	Large trucks 0%
Long range electric vehicles		57%	46%	67%	100%	100%	100%	Key limitation is charging and customer who would prefer ICE. Formula=(1-H)*(D+E)	
Plug-in hybrid electric vehicles		57%	46%	67%	100%	100%	100%	Same as long range	
Fuel cell vehicles (light)		8%	4%	8%	10%	10%	30%	Formula=(1-H)*K	
Fuel cell large trucks				30%	50%	50%	90%	Scenario setting	
Autonomous ride-share vehicles		6%	3%	6%	10%	15%	15%	Formula=J*F	

Table 4-5 Shares of different electric vehicle charging behaviours by 2050 based on limiting factor analysis

Limiting factor		Current Trajectory	Slow Growth	Net Zero	Sustainable Growth	Rapid Decarbonisation	Export Superpower	Rationale/formula
Customers accessing tariffs that support prosumer behaviour and system integration	L	20%	15%	25%	30%	35%	35%	Scenario assumption
Residential vehicles								
Home charging convenience profile		73%	78%	66%	59%	53%	53%	Residual
Home charging night aligned (non-dynamic)		4%	3%	5%	6%	7%	7%	Formula=0.2*L
Vehicle to home/grid (dynamic system-controlled charging)		12%	9%	18%	29%	35%	35%	Formula=D*E
Public charging highway fast charge		5%	5%	5%	5%	5%	5%	90%+ of driving is within 30km of home
Public charging solar aligned (non-dynamic)		6%	5%	6%	1%	0%	0%	Formula=0.8*(L-vehicle home/grid share)
Commercial vehicles								
LCV - Convenience / night		74%	79%	69%	65%	60%	60%	Non-highway kilometres. Formula=(1-L)*0.95
LCV - Daytime adjusted for solar alignment		19%	14%	23%	28%	32%	32%	Non-highway kilometres. Formula=L*0.95
LCV highway fast charge		8%	8%	8%	8%	8%	8%	Assume similar pattern to residential driving
Trucks & buses convenience / night		76%	81%	71%	67%	62%	62%	Non-highway kilometres. Formula=(1-L)*0.95
Trucks & buses solar aligned		19%	14%	24%	29%	33%	33%	Non-highway kilometres. Formula=L*0.95
Trucks & buses highway fast charge		5%	5%	5%	5%	5%	5%	Assume similar pattern to residential driving

4.6 Vehicle to home or grid

Once electric vehicles are established[14], they will represent a large battery storage resource. For example, if long-range electric vehicles are popular, each vehicle will represent around 100kWh of battery storage – some nine times larger than the average 11kWh stationary batteries that are marketed for shifting rooftop solar for households. It is therefore natural to consider whether this battery storage resource could be used either after its life on board a vehicle or during that life.

The average vehicle in Australia travels 11,000km per year. For a SREV of 200km range the battery size is around 40kWh, the average daily charge cycle will be 6.7kWh which is a depth of charge/discharge of around 17%. If a driver were to travel 3 times that distance each year the shelf life of the battery will run out before the cycle life. However, such a driver more than likely has a long-range electric vehicle (due to their higher average kilometres per day) where the daily depth of charge/discharge might be even lower.

Given the expected under-working of electric vehicle batteries it therefore makes sense to consider how to get more use out of the battery while it is on the vehicle. Household yearly average electricity demand is 6000kWh or 16.4kWh/day. As such, any full charged electric vehicle, short or long range, can cover the required power needs with room to spare for the daily commute. However, the most likely candidate for vehicle to home would be a long-range vehicle with around 100-120kWh battery storage. An LREV could deliver energy to a home and would on average only lose 100km or 20% or less of its 500+km range for the next day’s drive.

Vehicle to home would best suit a household that has access to charging via both home off-street parking at their normal place of daytime parking (i.e. at work or in a carpark). Apart from getting better utilisation out of an existing resource (the battery storage capacity in the vehicle), the other financial incentive to this arrangement is the potential that the vehicle can charge up at lower cost. This follows the general expectation that in the long term, as solar generation capacity increases, the lowest priced period for electricity from the grid will be around midday. The economics would also work well for the charging infrastructure provider. Instead of simply providing electricity for each cars’ daily driving needs (around $2/day) they can instead provide their car plus home needs ($6/day).

The process is achievable from a technical point of view with a more specialised connection to the home. At least one current manufacturer has taken this concept forward overseas (the Nissan Leaf).

The major difference with vehicle to grid is that it may push the boundaries further in terms of utilisation of the vehicle battery to meet system needs. Presumably the business model in this case would need to reach agreement with the vehicle owner on how much of the battery capacity can be accessed so that the owner’s transport needs are not compromised. Potential faster and deeper discharges could shorten the vehicle battery life. Nevertheless, the scale of electric vehicle battery capacity in the higher EV uptake scenarios (even accounting for low availability and only

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[14] AEMO’s scenario design assumes this occurs post 2030

access half the battery) could be sufficient to avoid the need for major large-scale battery deployment. As such, some compensation should theoretically be available to vehicle owners.

Our assumption is that commercial vehicles will not participate in either vehicle to grid or vehicle to business (home). The rationale is that higher duty vehicles will have less excess capacity that owners would be willing to make available to the grid. Commercial vehicles may still support the system through non-dynamic pricing (tariffs).

4.7 Shares of electric vehicle charging behaviour

Besides setting the technology adoption saturation levels, the maximum market shares identified in Table 4-4 are also applied, together with other assumptions, to determine what shares of different electric vehicle charging profiles should be applied by 2050 (Table 4-5). The key additional assumption is to assign the percentage of customers that are participating in tariffs or other incentives for prosumer and electricity system supporting behaviour (which is a scenario assumption).

For residential vehicles a small amount of highway charging is assumed consistent with the observation from many trip studies that around 90% of driving is within local areas (see BITRE 2015). The amount of home charging is calculated from the amount of off-street parking (calculated in Table 4-4). Charging at home is split between convenience and solar aligned charging based on the tariff and other incentives assumptions. The formula allows for another fraction of customers to participate in vehicle to grid or vehicle to home activities and charge during the day at their daytime place of parking. This represents the subset of people who have both off-street parking and access to public charging in that scenario.

Commercial charging profiles are aligned to the night time but could be incentivised to be aligned with solar generation should that become the new off-peak period to support electricity system efficiency (see Section 5.3 for charging profiles). Current tariffs faced by the commercial sector also incentivise avoiding peak periods. It is assumed that signing up to new tariffs or incentives could shift that part of charging which is not aligned with solar generation times into that time.

4.8 Transport demand

The future number of electric vehicles is partly determined by demand for transport and the number of road vehicles required to meet that demand. To develop our road vehicle demand projections, the process commences by projecting demand for passenger transport (passenger kilometres or pkm) and freight transport (tonne kilometres or tkm) across all transport modes. Passenger transport demand is a function of population, while freight demand is a function of economic growth. Next, assumptions are made about the share of transport delivered by each mode. In any normal year a simple extrapolation of past trends would be appropriate. For example, the aviation transport mode has been steadily gaining market share in passenger transport demand for decades. However, the COVID-19 pandemic has disrupted these trends and is likely to have some degree of ongoing impacts. As a conservative approach the mode shares for passenger transport are held constant at their current levels with only a slight leaning towards previous trends. Freight transport mode shares were less impacted by COVID-19 and so historical trends in mode share are allowed to continue. Additional discussion on the effects of COVID-19 on road vehicle kilometres per year is provided in Section 4.8.2 with specific assumptions in Table 4-6.

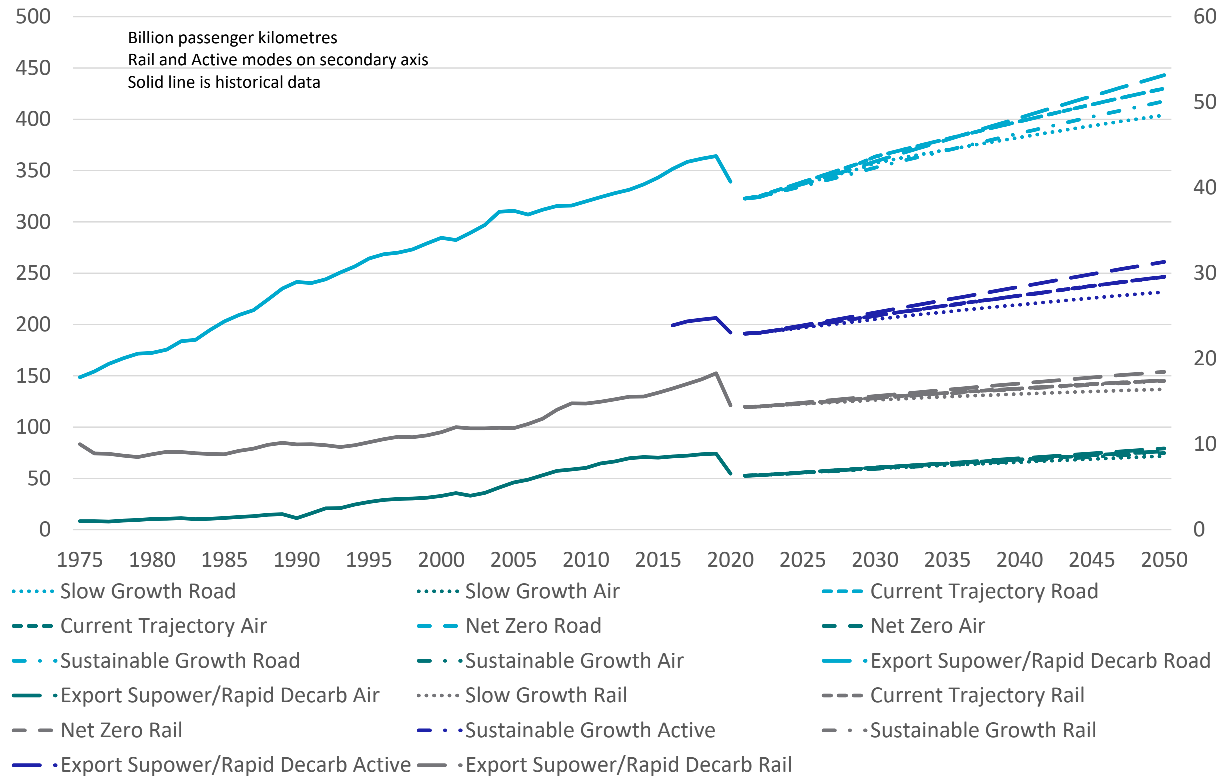

Figure 4-3 Historical and projected passenger transport demand

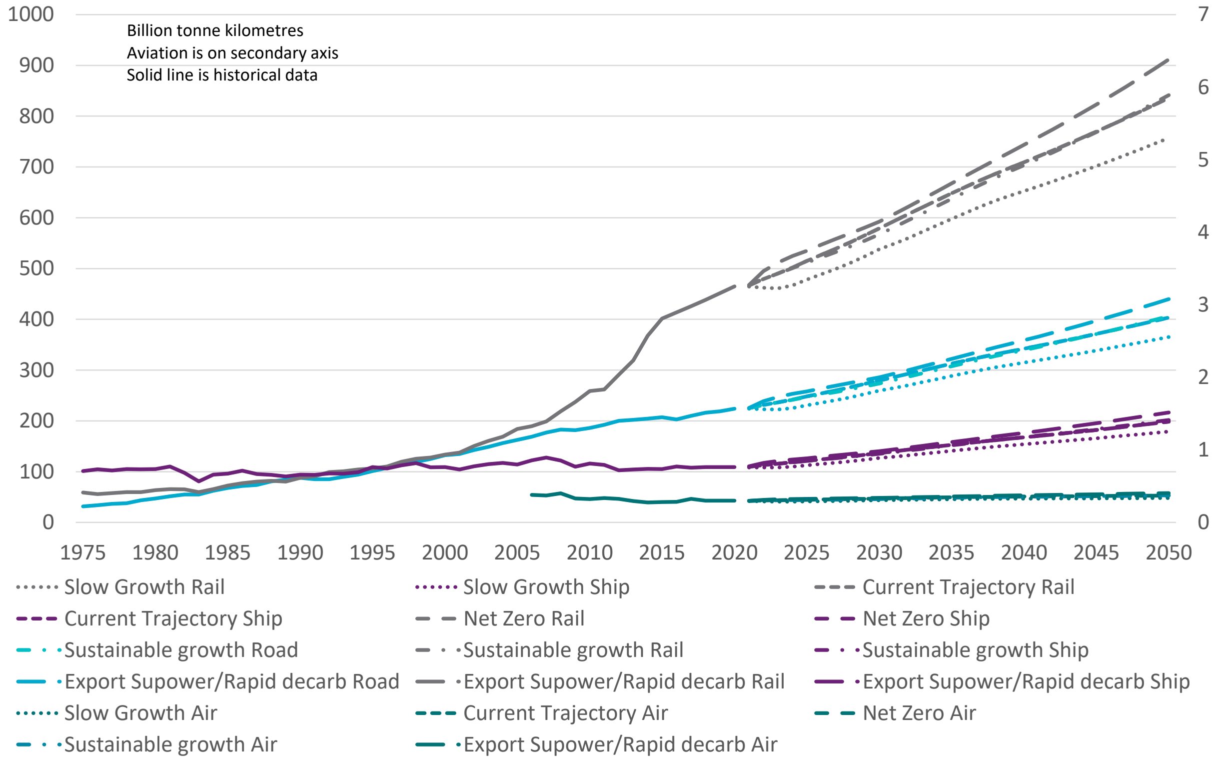

Figure 4-4 Historical and projected freight transport demand

The results of these passenger and freight transport demand projections are shown in Figure 4-3 and Figure 4-4. The reduction in passenger transport demand during the COVID-19 pandemic is strongly evident in the 2020 data. The data outlined in Figure 4-3 and Figure 4-4 are national, but the projections are developed for each state and account for different levels of disruption from COVID-19 by state.

To calculate road transport demand in vehicle kilometres CSIRO imposes a price elasticity response by tracking future road transport costs (based on an initial estimate of the vehicle mix). Views about autonomous vehicle adoption and the general level of vehicle utilisation are discussed below.

4.8.1 Autonomous vehicles

As part of vehicle demand modelling, the uptake of automated vehicles in both the light and heavy vehicle markets for private use and as ride share vehicles are projected. The main delay in adopting these technologies is achieving complete safety and technological feasibility. Otherwise, the benefits of time and wages saved from driving appear to be well above the vehicle cost on a whole-of-life basis. The projections assume different market sizes over time across the scenarios based around the general uncertainty to this new way of delivering road transport services.

Figure 4-5 shows the projected share of passenger and freight autonomous vehicles by scenario by 2050. Ride-share are disaggregated from privately owned autonomous vehicles. The total across all vehicle types range from less than 1% to 20% across all scenarios by 2050. Rideshare vehicles are of interest because they could reduce the total number of electric vehicles required on the road and is likely to impact the total energy consumed under each vehicle charge profile. Rideshare vehicles are only projected to reach a significant share in Sustainable Growth. While these percentages are relatively small, each rideshare vehicle displaces other vehicles depending on how successful they are in concentrating passengers into the rideshare vehicle. It is assumed the displacement is initially small but increases such that each rideshare vehicle displaces 2 non-rideshare vehicles by 2050 as the business model matures.

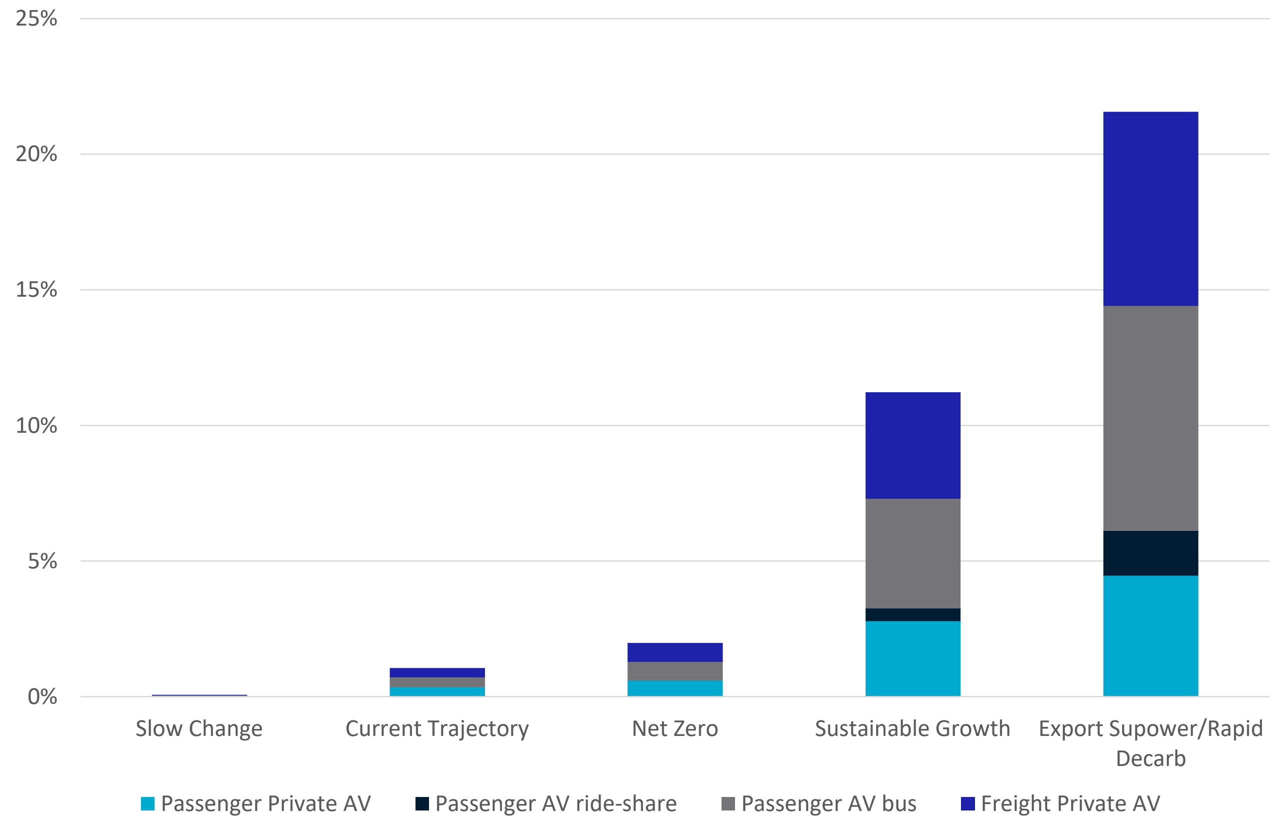

Figure 4-5 Share of passenger and freight autonomous vehicles in the road vehicle fleet by scenario by 2050

4.8.2 Vehicle utilisation and numbers

To convert road passenger transport demand to vehicle numbers requires assumptions to be made about average kilometres travelled per vehicle. According to ABS (2020), all passenger vehicle types (motorcycles, passenger cars and buses) experienced a significant reduction in all states (Figure 4-6) due to COVID-19. Buses suffered the strongest impact owing to the difficulty of social distancing for passengers within such a vehicle. Light commercial vehicles and trucks generally faired proportionally better with only modest reductions or increases in some states. In short, Western Australia, Northern Territory and the Australian Capital Territory had the least changes in vehicle utilisation.

The extent to which the COVID-19 pandemic will lead to sustained changes in vehicle utilisation is uncertain. The experience has demonstrated to employers and employees that working from home can be productively applied to some jobs. This has raised expectations that the option to work from home may be available to employees well beyond the period in which such arrangements are implemented purely for public health compliance reasons. The longer pandemic conditions persist, such arrangements will be normalised. Therefore, it is not unreasonable to expect that lower economic growth scenarios associated with lower population growth that implies a slower recovery from the pandemic would reduce and maintain lower vehicle utilisation into the future. Conversely, higher economic and population growth would suggest higher vehicle utilisation. It is considered that the incidence of using telepresence for work and other activities could increase as a greenhouse gas abatement strategy, particularly in scenarios with a net zero emissions target. Based on this reasoning, assumptions for changes in vehicle utilisation were developed and outlined in Table 4-6.

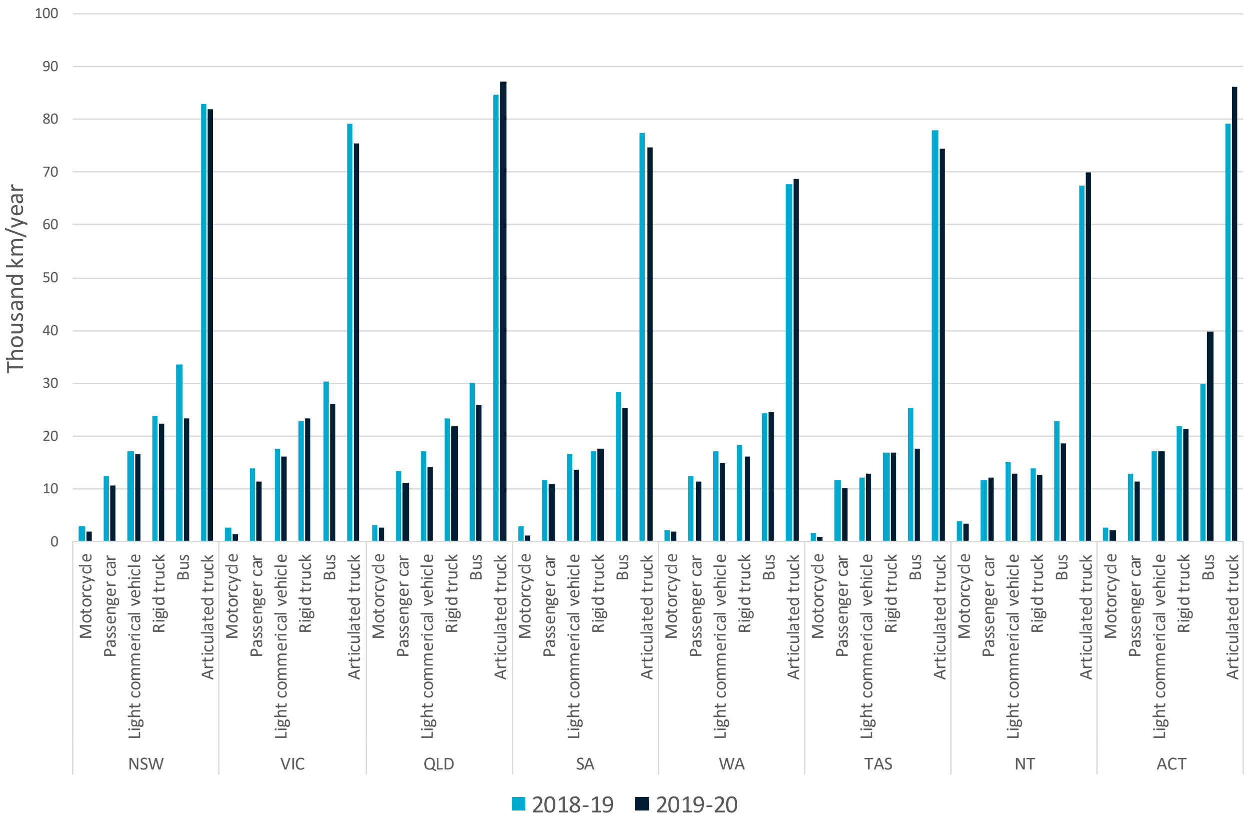

Figure 4-6 Comparison of 2018-19 and 2019-20 vehicle utilisation by vehicle type

Table 4-6 Assumed changes in vehicle utilisation and rationale

	Slow Growth	Current Trajectory	Net Zero	Sustainable Growth	Export Superpower	Rapid Decarbonisation
Extent to which vehicle utilisation returns to pre-COVID levels	75% of difference is recovered by 2030	75% of difference is recovered by 2030	75% of difference is recovered by 2030	25% of difference is recovered by 2030	25% of difference is recovered by 2030	25% of difference is recovered by 2030
COVID-19 has accelerated permanent shift to greater share working from home	Somewhat	Somewhat	Somewhat	Significantly	Significantly	Significantly
Climate policy ambitions encourage greater use of telepresence				Yes	Yes	Yes

Taking the passenger and freight kilometres projection in Figure 4-3 and Figure 4-4 and assumed average freight load and passengers per vehicle (the average is 1.57 for cars before adjusting for uptake of rideshare vehicles), the road vehicle kilometres travelled to meet passenger and freight tasks is calculated and presented in Figure 4-7. The demand for road vehicles is calculated by dividing through by vehicle utilisation and the result is shown in Figure 4-8.

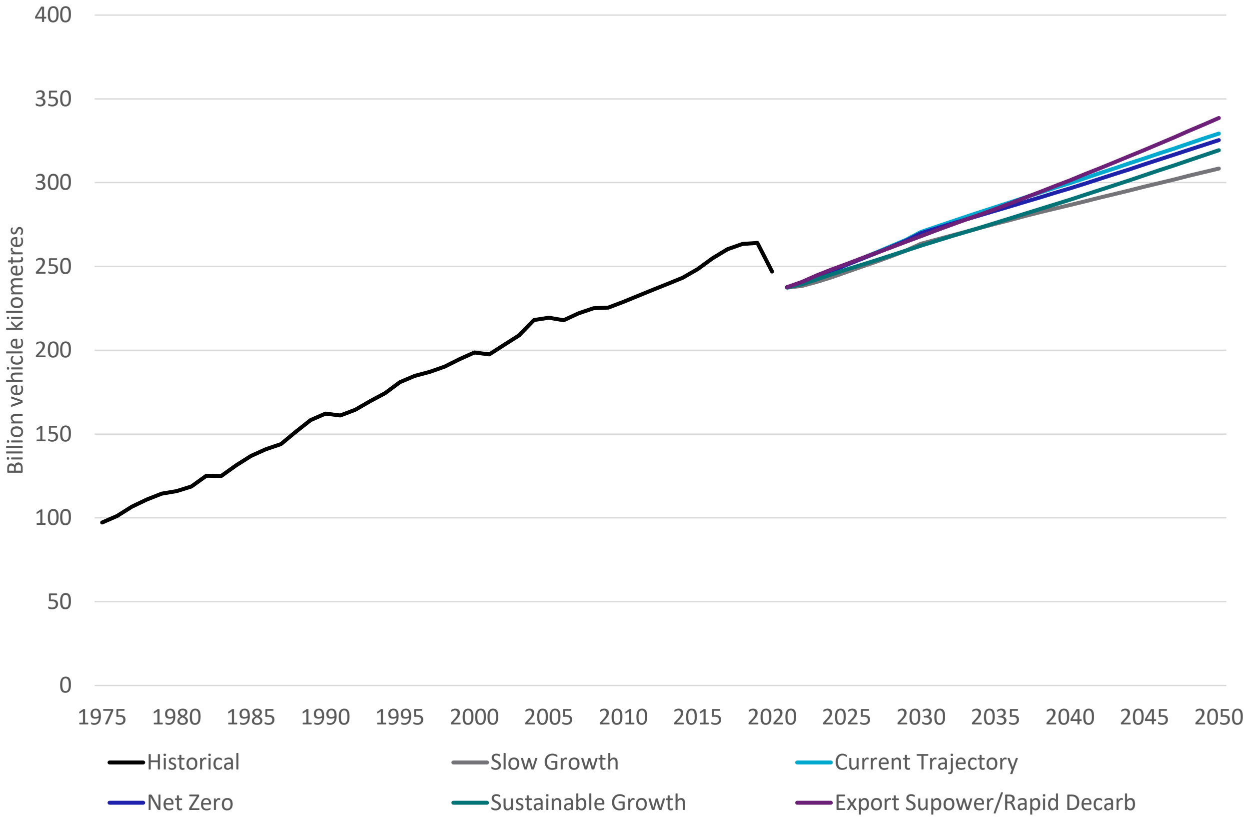

Figure 4-7 Historical and projected national road vehicle kilometres travelled, all road modes

The highest demand for travel is in Export Superpower and Rapid Decarbonisation reflecting stronger economic and population growth (which more than offsets greater use of telepresence). The Current Trajectory and Net Zero scenarios have lower economic growth and assumes less use of telepresence. Sustainable Growth assumes a greater use of telepresence than Current Trajectory and similar economic and population growth. While Slow Growth has the weakest economic and population growth.

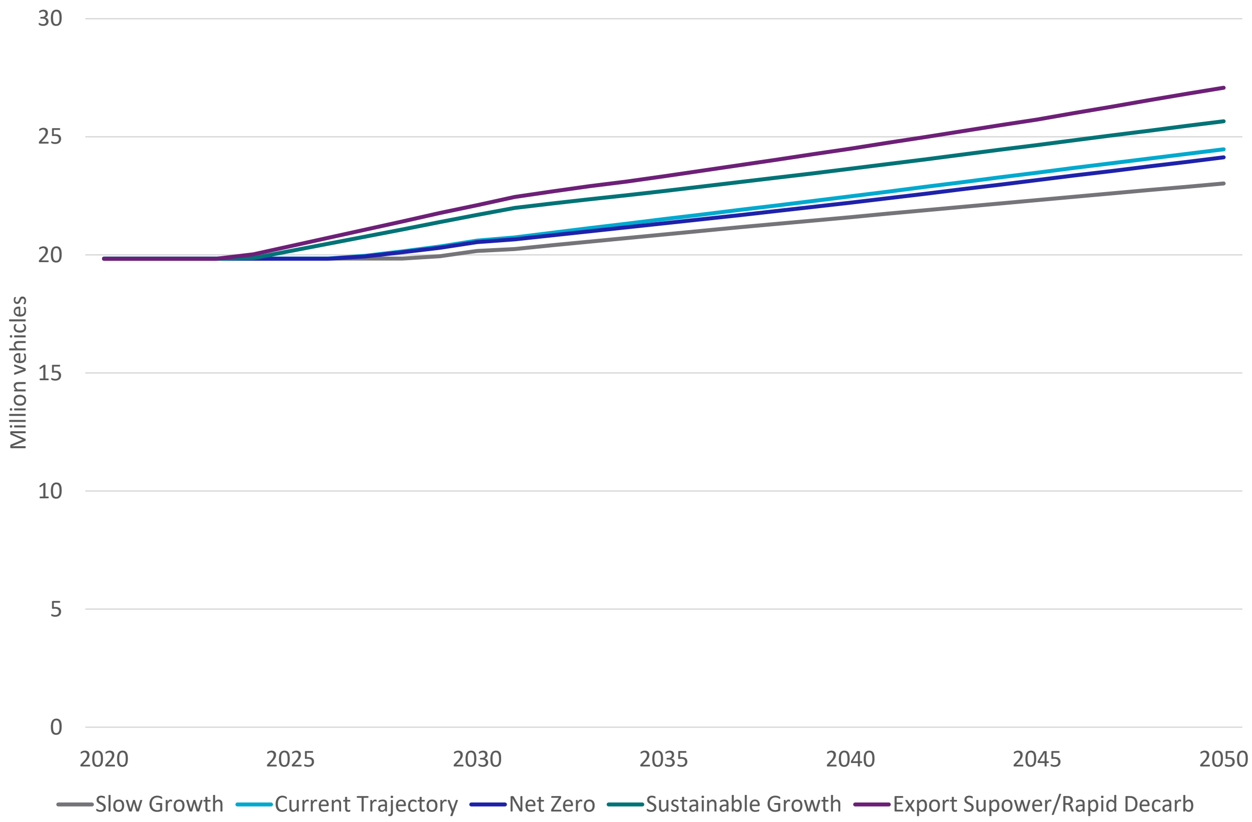

Figure 4-8 Projected national road vehicle fleet by scenario

4.9 Non-road electrification

The largest consumer of electricity in non-road transport is the passenger rail sector (around 3.3 TWh nationally). This can be in the form of heavy rail or light rail (such as Melbourne's Tram system). These services are delivered by state governments and as such the degree of investment in expanding this mode is subject to competing state budget demands. There are also limitations on competing land uses for new rail corridors (tunnels are a partial means around this issue where geology is suitable). Passenger loads in existing corridors can be increased through modification of rolling stock (e.g. more standing space, or double level). Freight rail could be partially electrified. The main limitation is the cost of providing electricity supply along freight rail routes, some of which are remotely located. There is also the sunk cost of existing diesel rail engines which could be converted to other low emission fuels. These constraints mean that electrification is expected to be low until technological advancements improve.

Up until recently aviation was not considered for electrification due to range limitations. However, the improvements in batteries, the success of electric-based drone technology in non-passenger applications and proliferation of transport-on-demand business models in cities, electrification of aviation is considered more plausible. Delivery models being considered are diverse and include hybrids (single electric engine added to aircraft with other conventional propulsion), pure electric with modified air frame, vertical aero propeller / helicopter designs, hydrogen fuel aircraft designs and electric on-ground taxiing power. However, it is unclear if any of these designs would ever replace more than a few percent of long-haul high passenger load aviation. It is more likely that electrification or hybrid engines will be adopted in shorter route low passenger load aviation.

The consideration of electrification of shipping is less common. This is because ships can use some of the lowest cost liquid fuels available at present, their diesel engines are more easily adaptable to alternatives such as very low sulphur fuel oils, LNG, biofuel, natural gas and hydrogen. The weight of batteries and range limitation of electricity remains an unsolved issue. Consequently, electrification of marine transport is not included in the projections.

The projections for passenger rail electricity consumption are based on the projected rail passenger demand in Figure 4-3 multiplied by the extrapolated trend in rail energy requirements per passenger kilometre. For rail freight and aviation electrification, CSIRO calculates their overall energy demand and convert a share of demand over to electricity according to assumptions that are presented in Table 4-7. These are a subjective assessment of technology readiness and overcoming limits to adoption based on the scenario narratives.

Table 4-7 Rail freight and aviation electrification assumptions

Scenario	Electrification commencement date		Maximum share by 2050
	Rail freight	Aviation	%
Slow Growth	2048	2047	3
Current Trajectory	2044	2042	5
Net Zero	2035	2030	7
Sustainable Growth	2035	2030	10
Export Superpower	2030	2027	20
Rapid decarbonisation	2030	2027	20

5 Projections results

In this section the projection results are presented here to 2055, as some of the assumptions relate to years after the required projection period, such as the timing of internal combustion vehicle deregistration in net zero emission scenarios. Some results in this section show all electric vehicles engine types and these includes hydrogen electric vehicles while other results only present battery electricity vehicles (BEVs). Selected CSIRO 2020 projections from AEMO's 2020 scenario projections (Slow Change, Central and Step Change) are reproduced here for the purposes of comparison (Graham et al., 2020).

5.1 Sales and fleet share

The projected sales and fleet shares for all electric vehicles compared to selected 2020 projections are shown in Figure 5-1 and Figure 5-2 respectively. Previously, the 2020 Step change scenario projections forced sales to reach 100% of electric vehicle by 2030 assuming there would be no internal combustion vehicle available due to either global manufacturers switching out of internal combustion vehicle supply or a government ban on sales of those vehicles (as has been announced in some international countries). It is becoming more likely that global vehicle manufacturers will no longer design and manufacturer internal combustion vehicles beyond a certain year. Public announcements on cessation dates largely lie in years between 2030 through to 2040. As the announcements are not universal with all car manufacturers, CSIRO now applies a range of 100% electric vehicle sales across the scenarios: 2035 for Export Superpower and Rapid Decarbonisation, 2040 for Sustainable Growth, 2050 for Net zero, and beyond 2055 for the remaining scenarios.

In comparison, the 2020 Central and Slow change scenarios had no 100% sales date and instead their sales saturated on the basis of assumed demographic and infrastructure constraints such as access to charging (apartment buildings, no driveway/garage buildings and rented dwellings being more difficult to arrange convenient home charging). The difference between the 2020 and the 2021 Current Trajectory and Slow Growth scenarios, is the 2021 projections assume these issues are slowly overcome and does not cause a sales saturation effect. They are overcome because, while the 100% sales date is much slower in comparison, CSIRO assumes it eventually does arrive and it becomes an obligation of all landlords and apartment builders to provide charging points in the future.

With historical scrappage rate in some states suggesting it may take up to 35 years to naturally retire all internal combustion vehicles from the fleet, in order to represent scenario where road transport emissions are eliminated, our approach does not solely rely on internal combustion vehicles being unavailable for sale. A second strategy, to meet targets, should the government choose, will be to set a date for disallowing registration renewal of internal combustion vehicles. Our expectation is that this approach would probably only be used with a lot of lead time (e.g. ten to fifteen years notice) so that current owners of internal combustion vehicles will be able to get value out of their assets before they are no longer able to be registered. As such the deregistration dates across the scenarios are set ten years after the 100% electric vehicle sales date. That is, 2045 for Export Superpower and Rapid Decarbonisation and 2050 for Sustainable Growth. For Net Zero, the date of 2055 is five years after the 100% electric sales data. This recognises that Net Zero aligns most closely with Current Trajectory in the first decade after a policy shift requires net zero emissions by 2050. It is assumed the road sector is not required to eliminate emissions by 2050 due to a later start in transforming the fleet but manages to achieve this goal five years later, by 2055, taking the pressure off the more difficult sectors for greenhouse gas emission abatement.

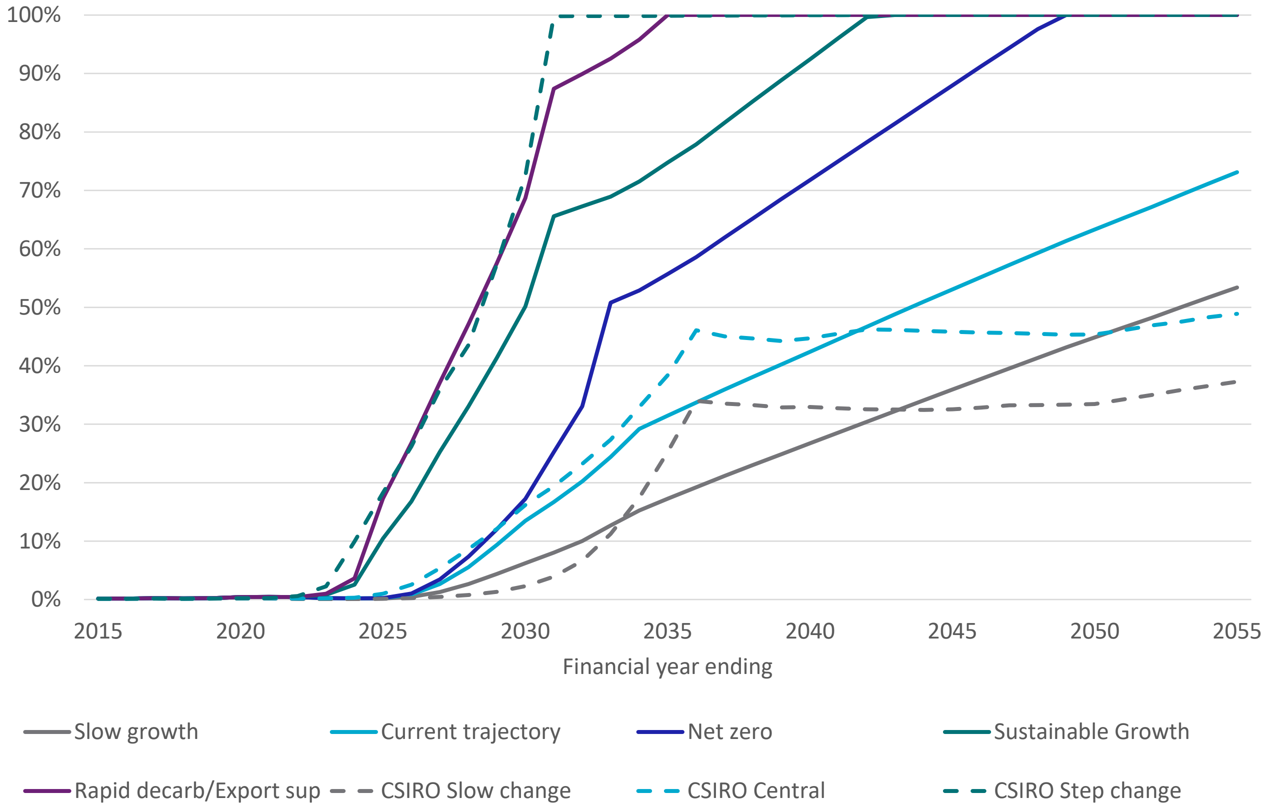

Figure 5-1 Projected sales share, all electric vehicles, compared to selected 2020 projections

Due to the different assumptions applied for vehicle cost reductions, both the sales and fleet share projections display different timing of initial uptake. Short range electric vehicles are assumed to cost the same as the equivalent size internal combustion vehicle by 2025 for Export Superpower, Rapid Decarbonisation and Sustainable Growth, by 2030 in Current Trajectory and Net Zero, and by 2035 in Slow Growth. The uncertainty around these dates is due to Australia's different approach to emission standards and mixed regional government approaches to subsidies and rebates. This means Australia's cost parity with EVs will differ to other international countries. In other regions of the world, such as Europe, internal combustion vehicle costs are rising to meet tighter emission standards and the range of vehicles available can be wider reflecting strong government incentives.

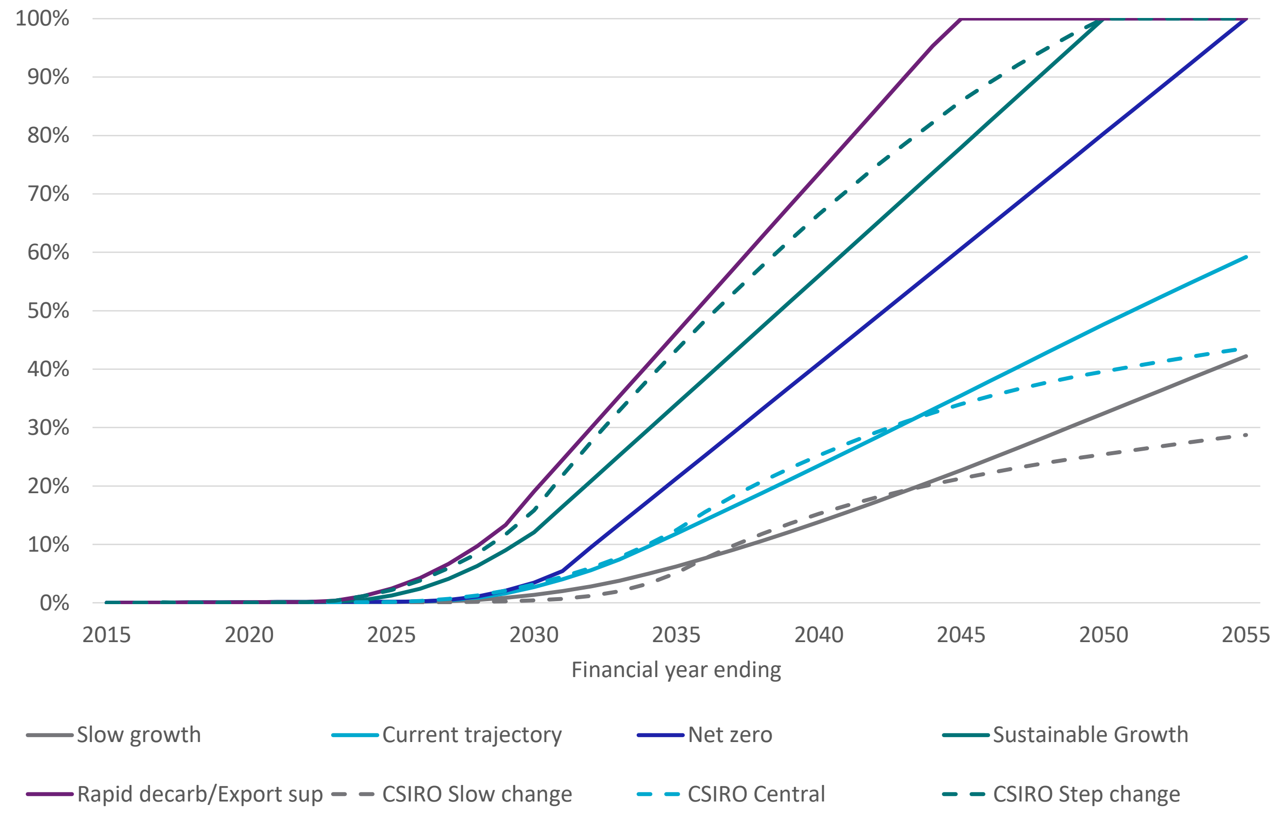

Figure 5-2 Projected fleet share, all electric vehicles, compared to selected 2020 projections

5.2 Electric vehicle numbers and consumption

The projected number of BEVs by scenario for the NEM and SWIS are shown in Figure 5-3 and Figure 5-4 respectively. When compared against the 2020 projections, vehicle numbers for Step Change and the early years of Central and Slow Change are higher than the equivalent 2021 scenarios (Sustainable Growth, Current Trajectory and Slow Growth). This is because population growth (a strong driver of passenger vehicle demand) is lower in the current projections owing to the impacts of the COVID-19 pandemic on immigration rates, a key driver for Australian population growth. Current Trajectory and Slow Growth exceed the 2020 projections in the 2040s, despite lower vehicle demand, as stronger sales and share assumptions are applied for this period. Population projections have changed more for the SWIS than the NEM overall.

A prominent feature in the vehicle number projections is a flattening of vehicle numbers for Export Superpower, Rapid Decarbonisation and Sustainable Growth in 2045 and 2050 respectively. This reflects the impacts of the deregistration of internal combustion vehicles assumptions in these scenarios. In the lead up to the point of deregistration, the road sector has to build up the stock electric vehicles to replace internal combustion vehicles that are being scrapped at a faster than normal rate in preparation for being no longer viable as road vehicles. Once the deregistration date has passed, scrappage rates return to normal, and the average age of existing vehicles is low, this precipitates a low rate of growth in new vehicles. To extend the graph further into the future, this process would also be evident in the Net Zero scenario from 2056 similar to the 2020 Step Change scenario that also has this feature.

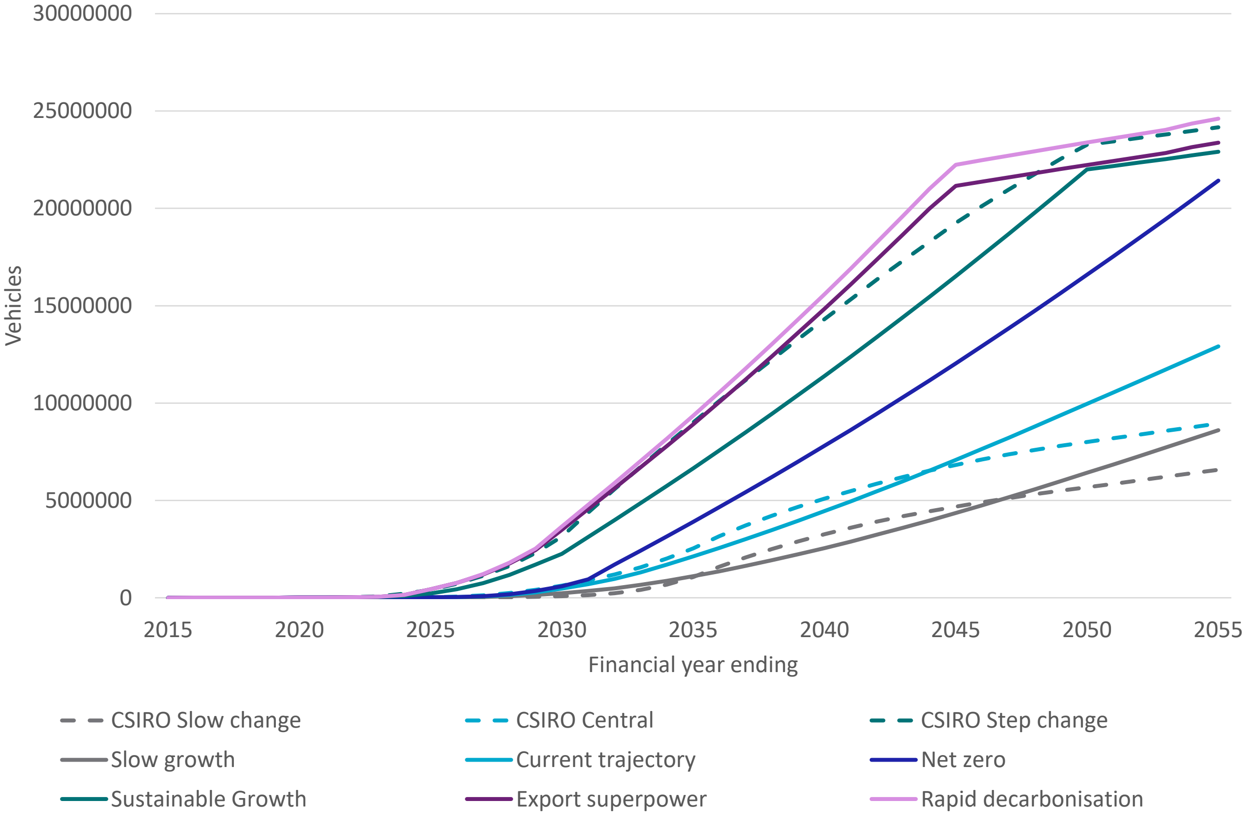

Figure 5-3 Projected number of BEVs in the NEM

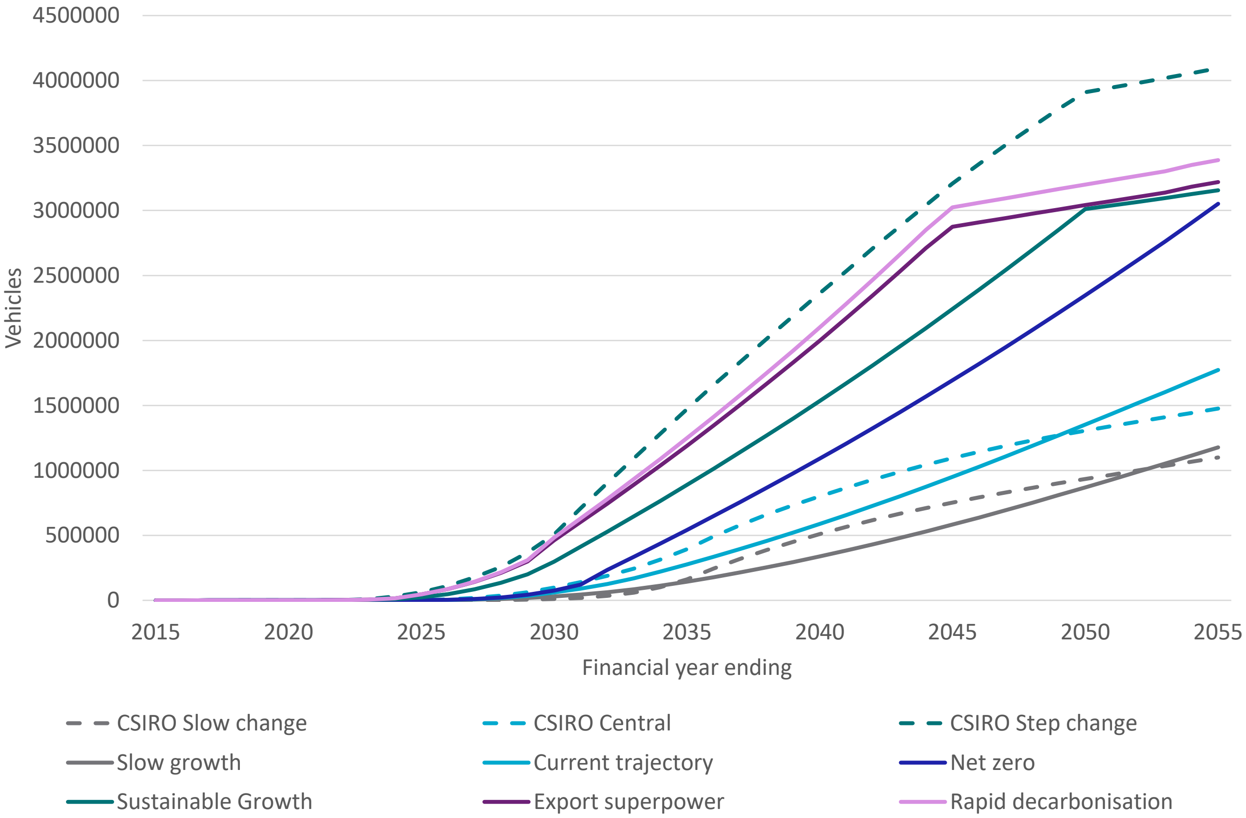

Figure 5-4 Projected number of BEVs in the SWIS

The number of electric vehicles is broken down by type for both the NEM and SWIS in Figure 5-5 and Figure 5-6 respectively. As a short-range battery electric vehicle (SREV) will not suit everyone's needs, their uptake is limited by maximum market share assumptions (an upper limit or saturation point on the technology adoption curve). The upper limit largely reflects the number of two vehicle households which may find it easier to have one short range vehicle. Long range battery electric vehicles (LREVs) compete with other long-range options such as plug-in hybrid electric vehicles (PHEVs) and fuel cell electric vehicles (FCEVs).

PHEVs are popular at present making up about a third of electric vehicle sales and are an effective means of overcoming the range issue and at the same time avoiding large expensive battery packs. However, given that LREVS are assumed to fall in cost over time (to the point where their whole cost of travel is comparable with internal combustion vehicles) and some scenarios assume restrictions on registration of internal combustion engine vehicles, by 2050, PHEVs no longer feature in the transport mix.

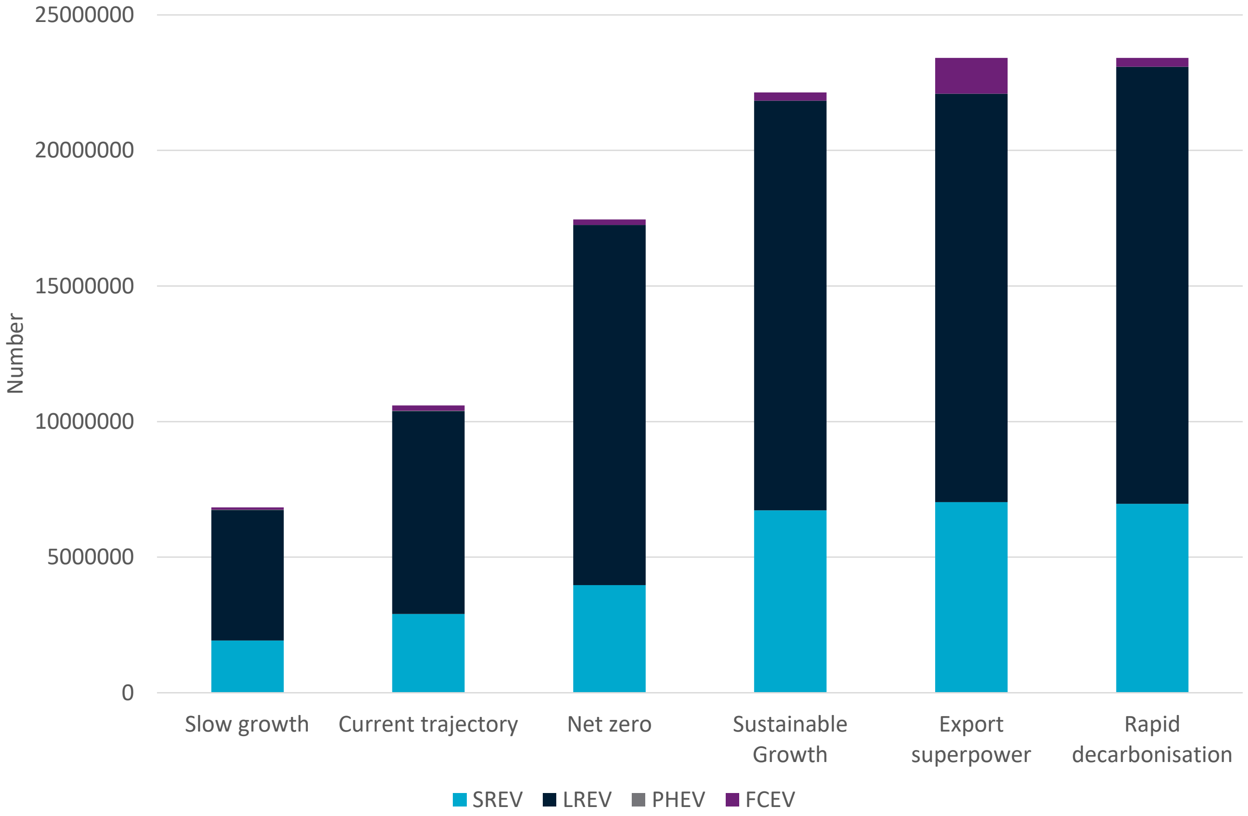

Figure 5-5 Projected number of vehicles in the NEM by 2050, all electric vehicles by type

FCEVs are a small proportion of vehicles in most scenarios. This is because FCEV costs are declining at a slower rate than battery electric vehicles and FCEV hydrogen. In addition, hydrogen refuelling infrastructure needs to be developed while electricity supply is ubiquitous across most sites. However, there are legitimate concerns about whether battery electric vehicle designs can cope with the heavy loads and distances of the articulated truck fleet. There are only 104,000 articulated trucks in Australia but they each use around 50 times the energy per year of a medium passenger vehicle. CSIRO allows FCEVs to take up a range of shares of this vehicle market depending on the scenario. In Export superpower, FCEVs are projected to capture the highest share of the market with a high allowable maximum market and assumed faster reductions in costs. It reaches about 70% share of the articulated trucks by 2050 and around 5% of the lighter vehicle market (the remainder being BEVs). Rapid Decarbonisation and Sustainable Growth have around 30% of articulated trucks being hydrogen driven with smaller proportions in the remainder of scenarios. There are no significant differences across the states except as driven by their share of the trucking fleet[15].

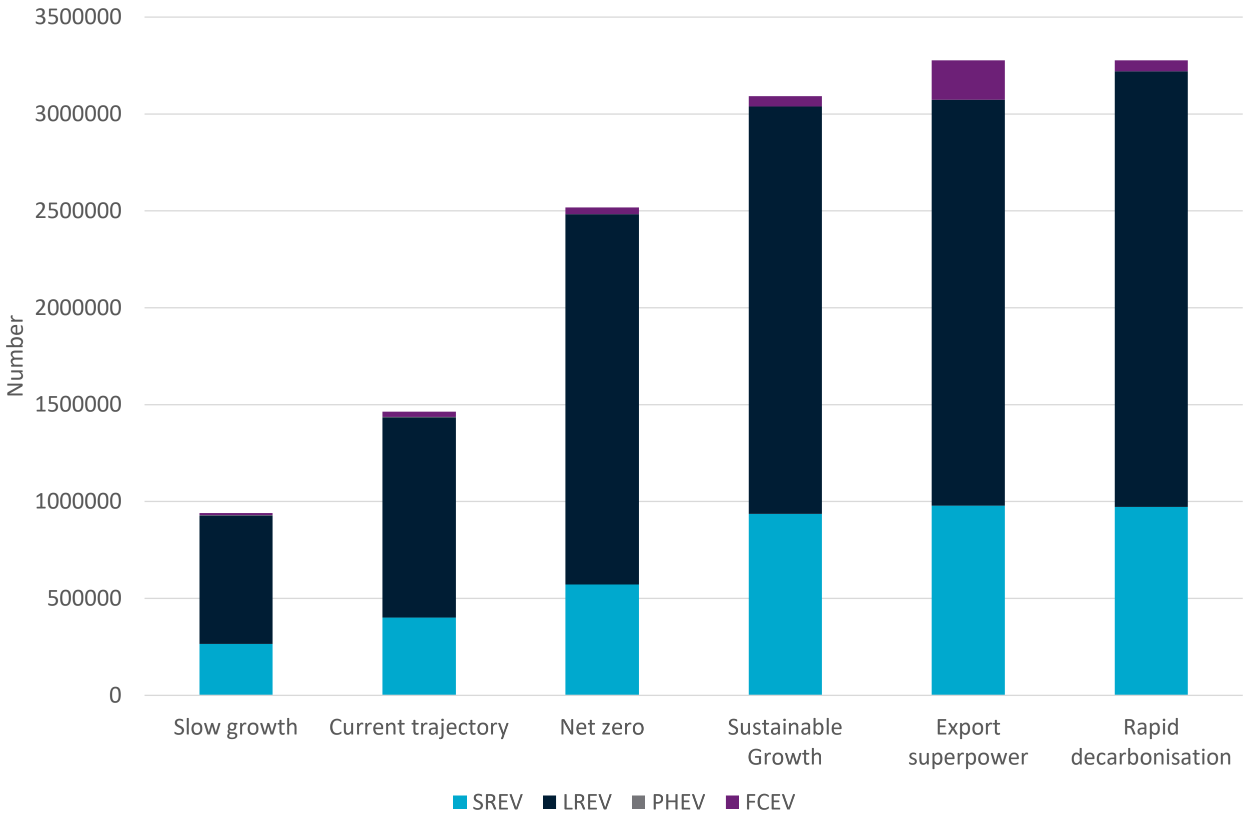

Figure 5-6 Projected number of vehicles in the SWIS by 2050, all electric vehicles by type

The trend in electricity consumption directly follows projected battery electric vehicle numbers and outlined in Figure 5-7 and Figure 5-8. Lower Australian population projections, lower vehicle numbers generally across the scenarios and lower kilometres travelled per day as a persisting trend[16] leads to lower electricity consumption compared to 2020 projections. The SWIS is more impacted by population than the NEM, but it showed a smaller response to COVID-19 in terms of changes in kilometres travelled per day. These opposing forces cancel out the changes in transport activities, such that the SWIS changes in the range of electricity consumption projection compared to 2020 is similar to the NEM.

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[15] That is, all states are assumed to reach the same share of fuel cell and electric vehicles, but they do not have the same share of trucks, cars and buses in their fleets

[16] Due to a greater use of telepresence and work from home arrangements, due to changes to the workplace environment.

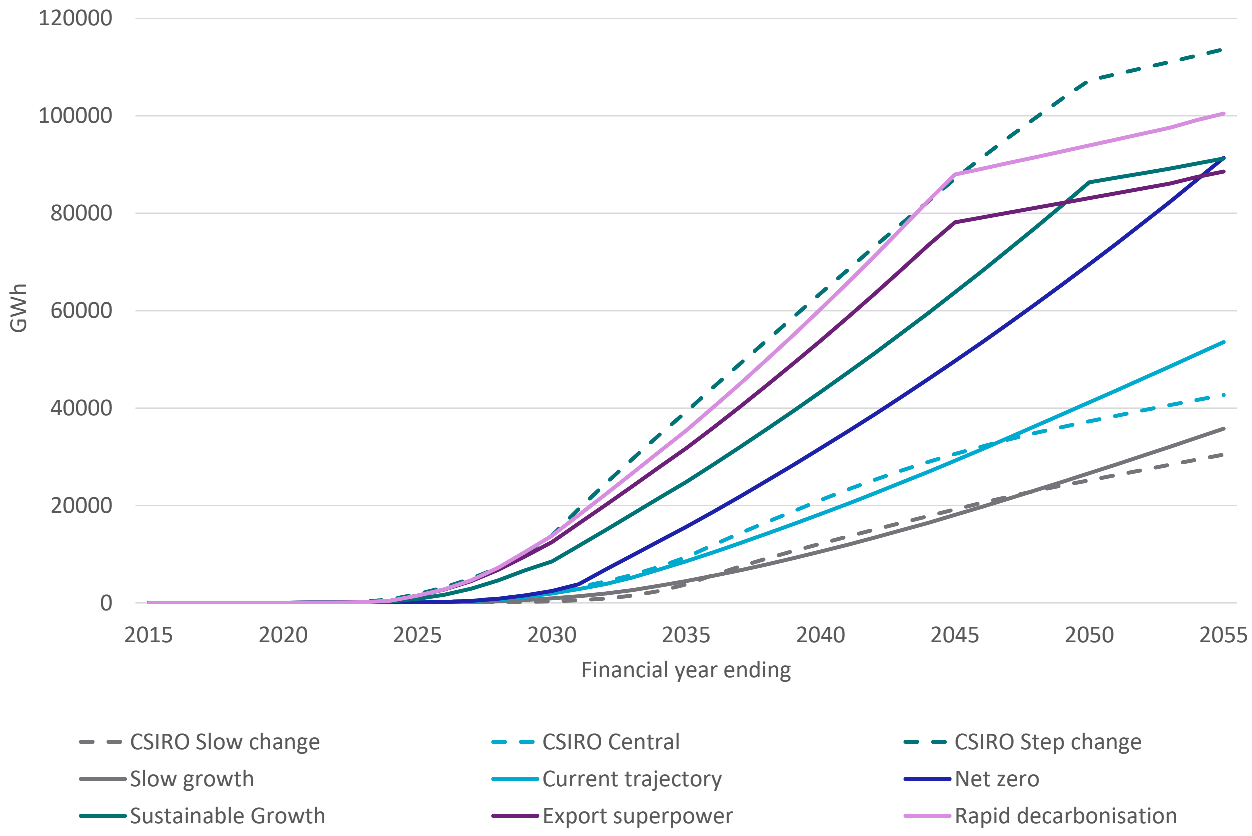


Figure 5-7 Projected electricity consumption by BEVs in the NEM

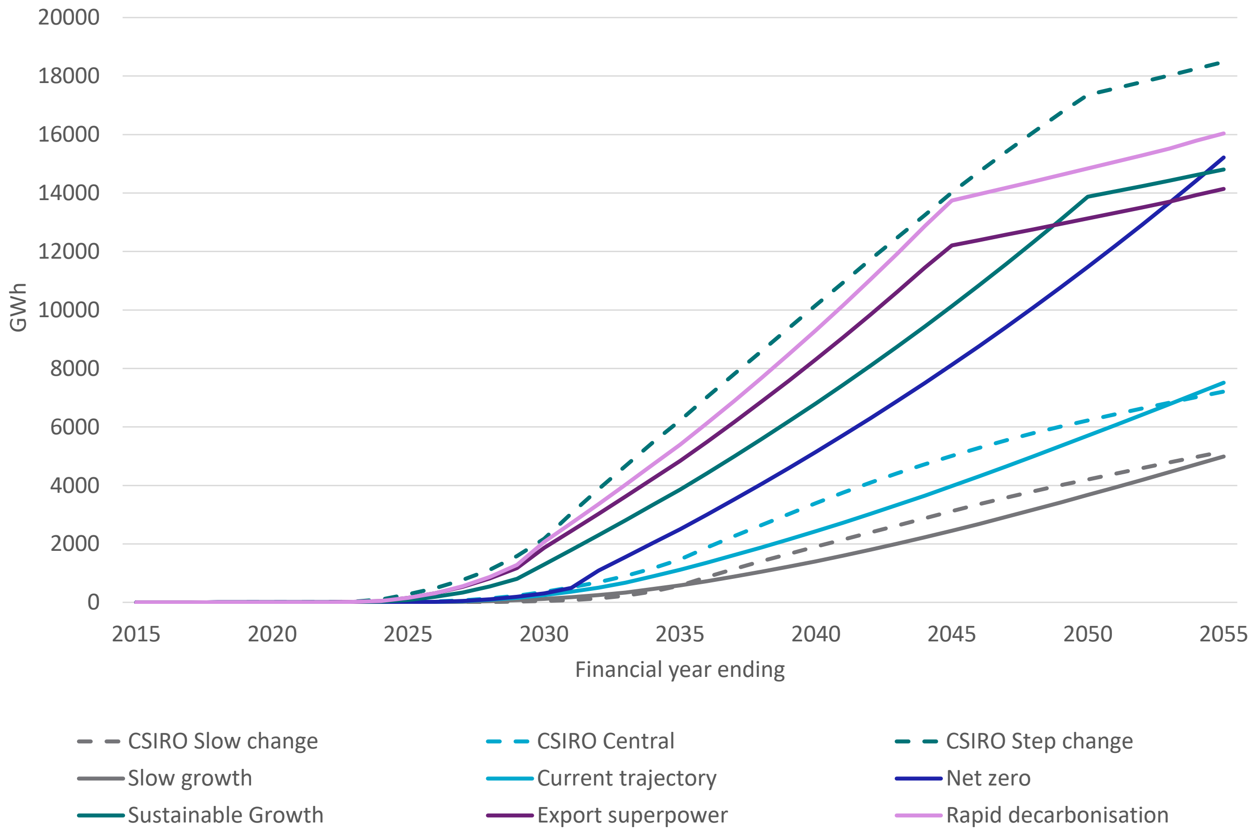


Figure 5-8 Projected electricity consumption by BEVs in the SWIS

5.3 Charging profiles

AEMO requires population or after-diversity charging profiles for electric vehicles. If there is no time of day tariff controlling or incentivising when to charge, then vehicle owners charge whenever it is convenient. The convenience profile shown in Figure 5-9 is based on Australian and international data (Roberts et al. 2016; Mader and Braunl 2013; Wang et al. 2016) and indicates a preference for plugging in after returning from work or other daytime activities. CISRO has adjusted previous studies to account for the rising power capacity of chargers which makes the evening charging peak higher than might have been observed in past trials with smaller capacity chargers.

The fast charger or highway charging profiles is aligned with traffic data. In Australia, New South Wales traffic data was provided to CSIRO by AEMO and was recently analysed by UTS. This analysis has allowed for an update of the fast/highway charging profile. The remaining profiles, day and night, are constructed based on how consumers might respond if they were given price signals to limit most of their charging to off-peak times during the night and day. The day profile is of most interest, where there is an expectation of high rooftop solar output.

More direct control of electric vehicle charging and discharging can be achieved through participation of owners in vehicle to home and vehicle to grid schemes. In this case, vehicle charging and discharging would look more like the operation of batteries for home or grid purposes and static versions of such behaviour have been provided to AEMO. These dynamic profiles should be estimated by AEMO to match daily needs of the home or system.

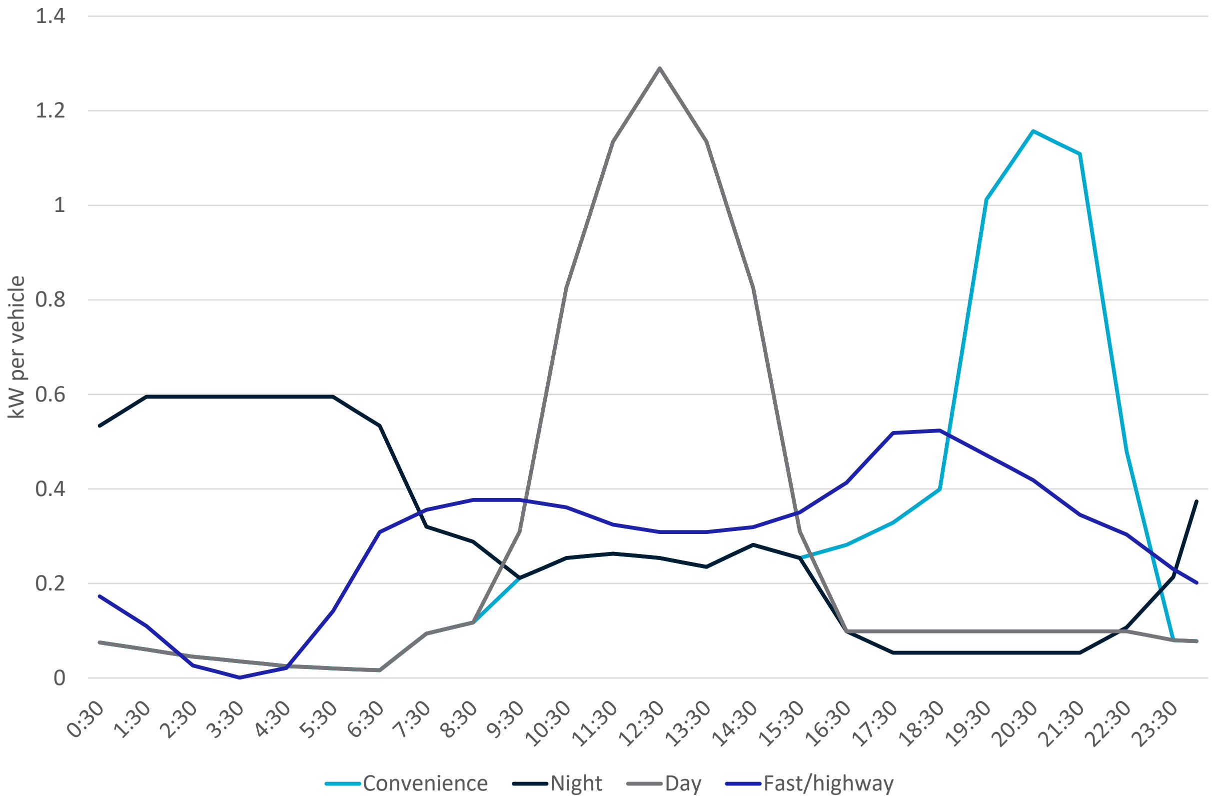


Figure 5-9 Average daily charging profiles for light passenger vehicles

Commercial vehicles such as trucks and buses undertake heavy duty load activities and, given demands on network connections and the greater prevalence of off-peak pricing, would be expected to be charging through the night mostly after the off-peak period (Figure 5-10). Hence the “night” and convenience profile are the same. They are also assigned day and fast/highway charging options.

Both the residential and commercial vehicle average daily charging profiles also consider further improvements in EVs across scenarios. Within a year, these profiles are adjusted for differences in weekend and weekday travel activity. Differences in monthly travel is also taken into account. Over the forecast period, there are also additional annual adjustments for changes in the efficiency of electric vehicles and in the average travelled distance per day.

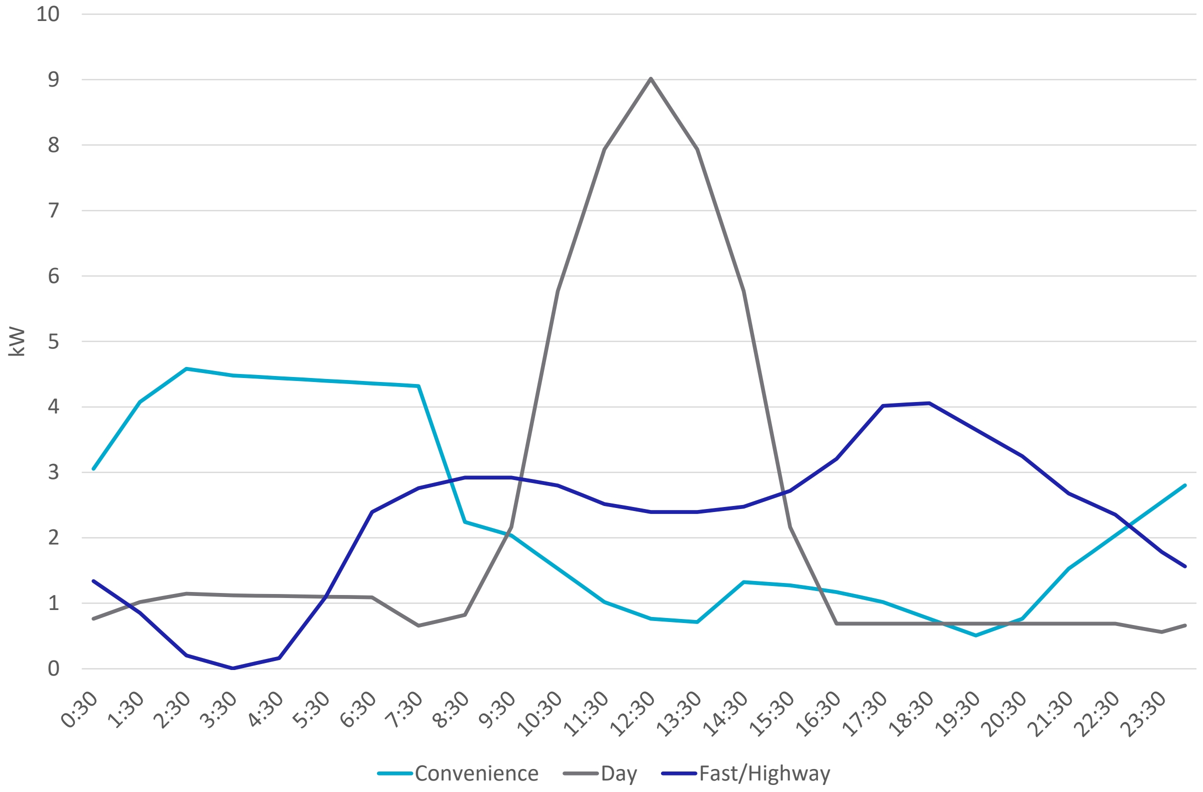
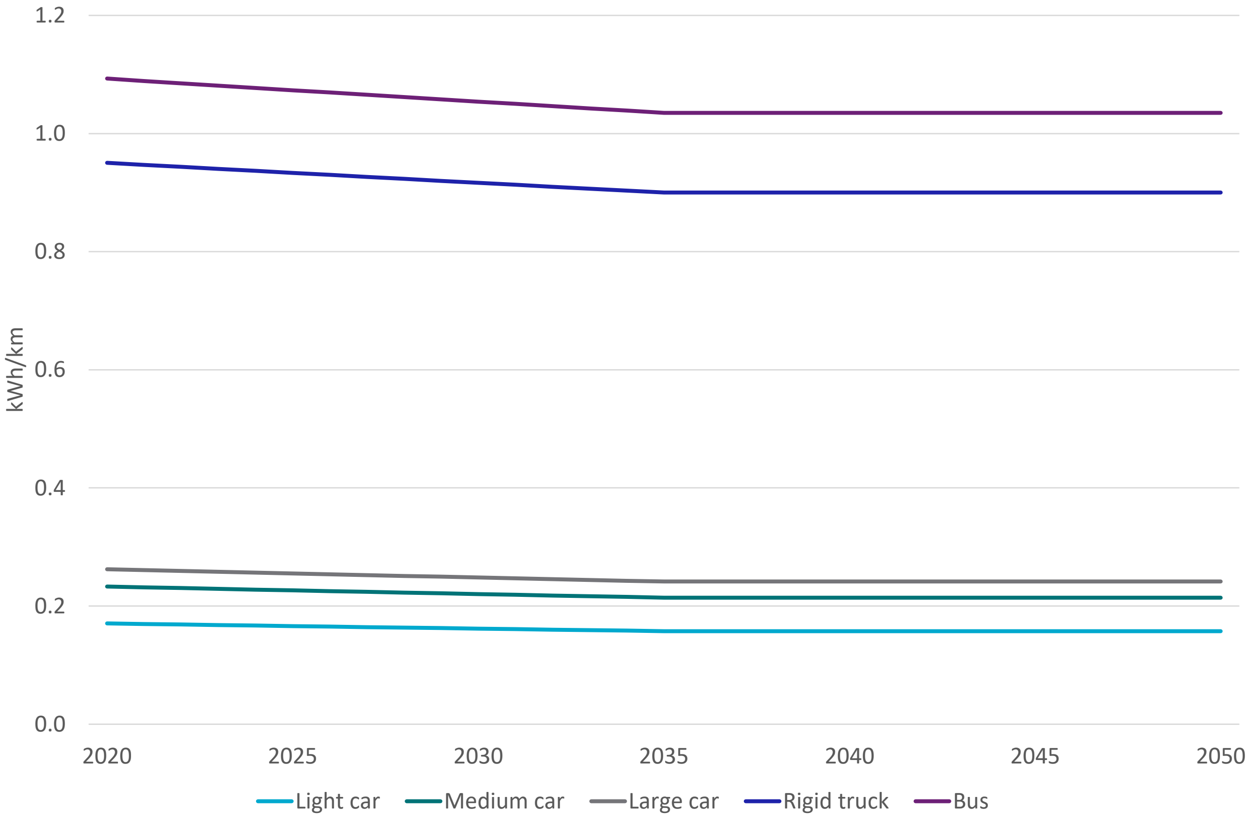


Figure 5-10 Average daily charging profiles for rigid trucks

Appendix A Additional data assumptions

A.1 Technology performance data

Figure A.1 shows the assumed vehicle fuel efficiency per kilometre by mode for electric vehicles.



Appendix Figure A.1 Electric vehicle fuel efficiency by road mode

The key determinant of fuel efficiency is vehicle weight with the lightest vehicles having the lowest electricity consumption per kilometre. The batteries which store the electricity adds to the total weight of each EV and CSIRO assumes further improvements in battery energy density over time. This leads to a steady improvement in fuel efficiency up to around 2035 and plateaus thereafter. Historically, internal combustion engine fuel efficiencies have plateaued unless there is significant fuel price pressure. That is, further engine efficiency improvements were traded off for better acceleration, better comfort, safety and space. CSIRO assumes electric vehicles will follow this similar trend.

Shortened forms

Abbreviation	Meaning
ABS	Australian Bureau of Statistics
ACCU	Australian Carbon Credit Unit
AEMC	Australian Energy Market Commission
AEMO	Australian Energy Market Operator
APVI	Australian Photovoltaic Institute
AV	Autonomous Vehicle
BOP	Balance of plant
CEFC	Clean Energy Finance Corporation
CER	Clean Energy Regulator
COVID-19	Coronavirus Disease of 2019
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DER	Distributed energy resources
EE	Energy Efficiency
ERF	Emissions Reduction Fund
EV	Electric Vehicle
FCAI	Federal Chamber of Automotive Industries
FCAS	Frequency Control Ancillary Services
FCEV	Fuel Cell Electric Vehicle
GDP	Gross Domestic Product
GSP	Gross State Product
hrs	Hours

ICE	Internal Combustion Engine
IPART	Independent Pricing and Regulatory Tribunal
ISP	Integrated System Plan
kW	Kilowatt
kWh	Kilowatt hour
LCV	Light Commercial Vehicle
LGC	Large-scale Generation Certificates
LRET	Large-scale Renewable Energy Target
LREV	Long-range electric vehicle
MW	Megawatt
MWh	Megawatt hour
NEM	National Electricity Market
NSG	Non-Scheduled Generation
PHEV	Plug-in hybrid electric vehicle
pkm	Passenger kilometres
PV	Photovoltaic
QRET	Queensland Renewable Energy Target
RET	Renewable Energy Target
SA2	Statistical Area Level 2
SGSC	Smart Grid Smart Cities
SREV	Short-range electric vehicle
STC	Small-scale Technology Certificates
SWIS	South-West Interconnected System
tkm	Tonne kilometres

TOU	Time-of-use
TWh	Terrawatt hour
UNFCCC	United Nations Framework Convention on Climate Change
VPP	Virtual Power Plant
VRE	Variable Renewable Energy
VRET	Victorian Renewable Energy Target
WEM	Western Electricity Market

References

Australian Bureau of Statistics (ABS) 2020, *Survey of motor vehicle use, Australia, 12 months ended 30 June 2020*, ABS.

Australian Energy Market Commission (AEMC) 2012, *Directions paper: Power of choice - giving consumers options in the way they use electricity*, AEMC.

Australian Institute of Health and Welfare (AIHW) 2017, *Australia's welfare 2017*, AIHW, Australia

Bass, F.M., 1969. A New Product Growth for Model Consumer Durables. *Management Science*, vol. 15, pp 215-227.

BCG 2015, *Revolution in the driver's seat: The road to autonomous vehicles* https://www.bcg.com/en-au/publications/2015/automotive-consumer-insight-revolution-drivers-seat-road-autonomous-vehicles.aspx

Bureau of Infrastructure Transport and Regional Economics (BITRE) 2015, *Australia's commuting distance: cities and regions*, BITRE, Canberra.

Chen, L., Huang, X., Chen, Z. and Jin, L. 2016, Study of a new quick-charging strategy for electric vehicles in highway charging stations, *Energies*, vol. 9, p744.

Climate Change Authority 2014, *Light vehicle emission standards for Australia*, http://climatechangeauthority.gov.au/reviews/light-vehicle-emissions-standards-australia

CSIRO and Energy Networks Australia 2017, *Electricity Network Transformation Roadmap: Final report*, ENA, Canberra.

FCAI (Federal Chamber of Automotive Industries) 2020, *VFACTS report: New vehicles sales*, FCAI.

Graham, P.W. and Havas, L. 2020, *Projections for small-scale embedded technologies*, CSIRO, Australia.

Higgins, A., McNamara, C. and Foliente, G. 2014, Modelling future uptake of solar photo-voltaics and water heaters under different government incentives, *Technology forecasting and social change*, vol. 83, pp 142-155.

Higgins, A., Paevere, P., Gardner, J., Quezada G. 2012, Combining choice modelling and multi-criteria analysis for technology diffusion: An application to the uptake of electric vehicles, *Technological Forecasting & Social Change*, vol. 79, pp 1399–1412

KPMG 2018, *Automated and zero emission vehicle infrastructure advice: Transport modelling*, Infrastructure Victoria.

Mader, T. and Bräunl, T. 2013, *Western Australian electric vehicle trial 2010-2012*, http://therevproject.com/trialreport.pdf.

Roberts, D.A. 2016, *My electric avenue: Learning and next steps*, EA Technology

Rogers E., 1962. *Diffusion of Innovations*. Glencoe: Free Press

Stenner, K., Frederiks, E., Hobman, E. V., and Meikle, S. 2015, *Australian consumers' likely response to cost-reflective electricity pricing*. CSIRO, Australia

Victorian Government 2013, *Creating a market: Victorian electric vehicle trial mid-term report*, State Government of Victoria, Melbourne.

Wang, H., Huang, X., Chen, L. and Zhuo, Y. 2016, *Highway Electric Vehicle Charging Load Prediction and its Impact on the Grid*, 2nd International Forum on Electrical Engineering and Automation (IFEEA 2015).

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