ENERGY
www.csiro.au

Projections for small scale embedded energy technologies

Report to AEMO

Paul Graham, Lisa Havas, Thomas Brinsmead and Luke Reedman

June 2019

Citation

Graham, P.W., Havas L., Brinsmead, T. and Reedman, L. 2019, *Projections for small scale embedded energy technologies*, Report to AEMO, CSIRO, Australia.

Copyright

Important disclaimer

Contents

Figures

Tables

Acknowledgments

This work benefited from input of staff from AEMO, two CSIRO reviewers and stakeholders who participated in the Forecasting Reference Group and internal referees. Any errors or omissions remain the responsibility of the authors

Executive summary

This report provides projections of small-scale embedded technologies for five scenarios which include solar photovoltaic systems (solar PV), battery storage and electric and fuel cell vehicles. The projections data includes installations, capacity, location and the operational profiles of batteries and electric vehicles. The projections are for the purpose of assisting AEMO in producing electricity consumption and maximum/minimum demand forecasts for AEMO’s 2019 electricity forecasting insights and related documents.

CSIRO employs a consumer technology adoption curve approach to developing the projections. This approach is particularly useful in the context of consumer investment decision making because it provides a way of accounting for financial and non-financial aspects of decisions. It allows for the existence of early adopters who will invest even when the payback period is beyond the life of the technology. It allows for main stream adoption where the payback period is within a reasonable range. It also allows for the existence of late followers who will not invest even when the payback period is very short because they may be constrained by infrastructure or personal preferences.

Given the continued attractive payback period for rooftop solar, its continued adoption is within the mainstream part of the adoption curve. Consequently, rooftop solar projections are the least uncertain and most match previous CSIRO projections for this technology. Larger scale solar generation in the 1MW to 30MW range is more uncertain and is divergent by state owing to different levels of financial assistance offered to large scale solar generation in support of renewable energy targets. The recent large decrease in the price of large scale generation certificates has reduced the outlook for solar in this size range.

Battery storage and electric and fuel cell vehicle adoption remain highly uncertain given their low foothold but large potential markets in Australia. They remain in the early adopter phase and emergence from this phase depends on technology cost projections. Correspondingly the projected range of uptake for these small-scale technologies is wider. Governments are starting see both battery storage and electric vehicles as areas which could benefit from increased government support programs.

The development of operational profiles for battery storage and electric vehicles is difficult in isolation from market feedback. The way customers operate their distributed energy resources will impact the market and in response the market may adjust the price signals to customers to incentivise operation that improves the efficiency of the electricity system. Completing this loop is not within the scope of this report. Instead we make a number of assumptions. We assume that avoiding adding to load during the peak evening period will always be of value, that shifting demand to the night time period is still valued in the medium term and that shifting load to the day time period will be most valued in the longer term due to the increasing amount of solar generation. The variety of battery and electric vehicle profiles included are designed to respond to these value propositions. We also provide some guidance as to which combination of profiles we expect to be active over time in each scenario.

1 Introduction

This report was commissioned by AEMO who require projections of small-scale embedded technologies which include solar photovoltaic systems (solar PV), battery storage and electric and fuel cell vehicles. The projections data includes installations, capacity and the operational profiles of batteries and electric vehicles. The purpose of the projections is to assist AEMO in producing electricity consumption and maximum/minimum demand forecasts for AEMO's 2019 electricity forecasting insights and related documents.

The projections are provided for five scenarios: Neutral, Slow change, Fast change, High DER and Low DER which were developed with AEMO based on their initial descriptions and an extended set of scenario drivers specific to distributed energy resources (DER) developed further in this report. The scenario data assumptions included input from AEMO on drivers such as customer growth, gross state product and electricity prices. CSIRO also developed other scenario data assumptions drawn from a range of other relevant drivers, depending on the technology.

The projections are required at a state level from 2018-19 to 2050-51. For Western Australia and Northern Territory, only the South West Interconnected System (SWIS) and Darwin-Katherine Interconnected System (DKIS) are included. Some projections have been supplied to AEMO at the postcode level. However, this report mostly focusses discussion on state level results.

The solar PV projections are separated by size and market segment as follows: residential (less than 10kW), commercial 10 to 100kW, commercial 100kW to 1MW, commercial 1MW to 10MW and commercial 10MW to 30MW. The first two segments are generally rooftop solar systems and are eligible to receive funding under the Small-scale Renewable energy Scheme (SRES). Battery storage projections are also provided under these two segments with two sizes for commercial systems.

The last three solar segments are referred to as Non-scheduled Generation (NSG) and may receive funding under the Large-scale Renewable Energy Target (LRET). In previous projections (Graham et al. 2018) a sixth segment which is standalone power systems (SAPS) or off-grid systems was included combining solar PV, battery storage and petroleum based generators. In this report we replace this category with vehicle to home electricity. This category offers the potential to provide most household electricity needs but without the need for the noise and local air emissions of a generator.

The market segments for electric vehicles include three engine configurations: Short range (<300km) and long range (>500km)[1] 100% electric (SREV and LREV) and plug in hybrid electric (PHEV). The vehicle types include passenger vehicles (large, medium and small), light commercial vehicles (large, medium and small), trucks and buses.

[1] The focus on the short and long range is for the purposes of capturing different vehicle price points and infrastructure constraints with respect to range. Whilst not modelled explicitly, we recognise mid-range electric vehicles may also fill a market niche. For the purposes of this report mid-range adoption can be understood as a subset of long range.

The report describes the projection methodology, scenario drivers and data assumptions and projection results. The appendices also describe additional data assumptions and maps of sub-state results.

2 Methodology

2.1 Adoption projections method overview

CSIRO applies a common projection methodology for electric vehicles, storage and all solar panels below 100kW. We regard these technology markets as “consumer” markets in the sense that investment decisions are driven by a combination of financial and non-financial drivers so that adoption will broadly follow the consumer technology adoption curve[2]. For large solar systems we take the view that such decisions should be regarded as more pure financial investment decisions and therefore we apply a mostly financially driven projection method.

2.1.1 Adoption in “consumer” technology markets

The consumer technology adoption curve is a whole of market scale property that we can exploit for the purposes of projecting adoption, particularly in markets for new products. The theory posits that technology adoption will be initially 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).

In the last 50 years, a wide range of market analysts seeking to use the concept 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. Payback periods are relatively straightforward to calculate and compared to price also capture the opportunity cost of staying with the existing technology substitute. A more difficult task is to identity the set of non-price demographic or other factors that are necessary to capture other reasons which might motivate a population to slow or speed up their rate of adoption. CSIRO has previously studied the important non-price factors and validated how the approach of combining payback periods and non-price factors can provide good locational predictive power for rooftop solar and electric vehicles (Higgins et al 2014; Higgins et al 2012).

In Figure 2-1 we highlight the general projection approach including some examples of the types of demographic or other factors that could be considered for inclusion. We also indicate an important interim step, which is to calibrate the adoption curve at appropriate spatial scales (due to differing demographic characteristics and electricity prices) and across different customer

[2] The key non-financial drivers considered by commercial customers for below 100kW systems are whether they own their premises (i.e. the well-known split incentives issue between landlords and renters) and competing priorities. These may apply at larger scale installations but to a lesser degree as large business have more control of their sites and energy is more likely to be a larger share of their costs, making it a higher priority.

segments (due to differences between customers' electricity load profiles which are discussed in Appendix A, travel needs, fleet purchasing behaviour and vehicle utilisation).

Once the adoption curve is calibrated for all the relevant factors we can evolve the rate of adoption over time by altering the inputs according to the scenario assumptions. 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 roof space or educational attainment in a region will result in different adoption curve shapes (particularly the height at saturation). Data on existing market shares determines the starting point on the adoption curve.

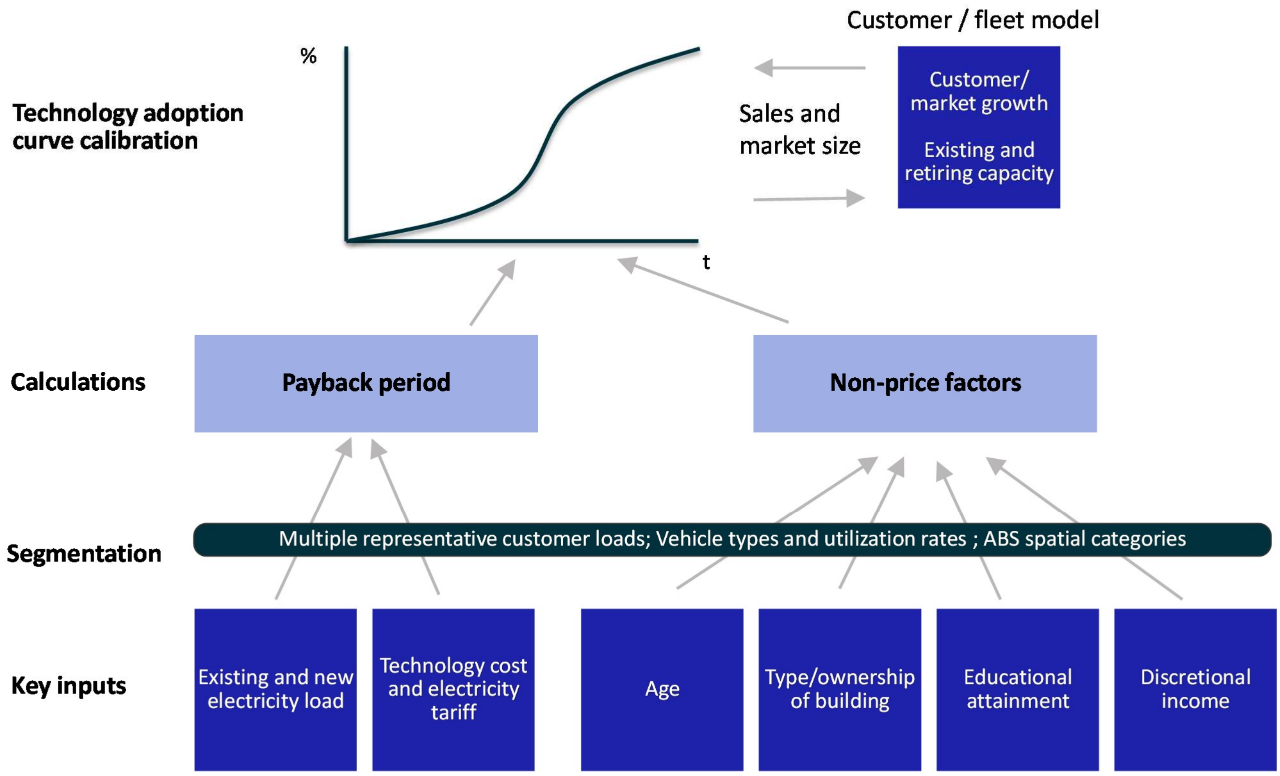


Figure 2-1: Projection methodology overview

The methodology also takes account of the total size of market available 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 are influenced by population growth, economic growth and transport mode trends and we discuss the latter further in the scenario assumptions section. While we may set a maximum market share for the adoption curve based on various non-financial constraints, maximum market share is only reached if the payback period falls. 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) as this matches most of the available demographic data. However, we convert the technology data back to postcodes or aggregate up to the state level as required.

2.1.2 Adoption of larger technology investments

For solar panel sales and capacity above 100kW, we employ a different approach. The difference in approach is justified on the basis that larger projects require special purpose financing and, as such, are less influenced by non-financial factors in terms of the decision to proceed with a project. In other words, financiers will be primarily concerned with the project achieving its required return on investment when determining whether the project will receive financing. Commercial customer equity financing is of course possible but it is more common that businesses have a wide range of important demands on available equity, so this is only a very limited source of funding (as compared to being the main source of small scale solar investment).

The projected uptake of solar panels above 100kW is based on determining whether the return on investment for different size systems meets a required rate of return threshold. If they do, investment proceeds in that year and region. Electricity prices and any additional available renewable energy credits in each state or territory will therefore be one of the stronger drivers of adoption. Where investment is able to proceed we impose a build limit rate based on an assessment of past construction rates and typical land/building stock cycles. Figure 2-2, Figure 2-3 and Figure 2-4 show the historical total deployment in each of solar plants in the 0.1MW to 1MW, 1MW to 10MW and 10MW to 30MW ranges respectively (source from APVI (2019)). They indicate the trends in build rates across each state. Deployment activity is most frequent and more evenly spread across states in the smaller ranges, particularly 0.1MW to 1MW. 10MW to 30MW plant are less frequent and concentrated in New South Wales.

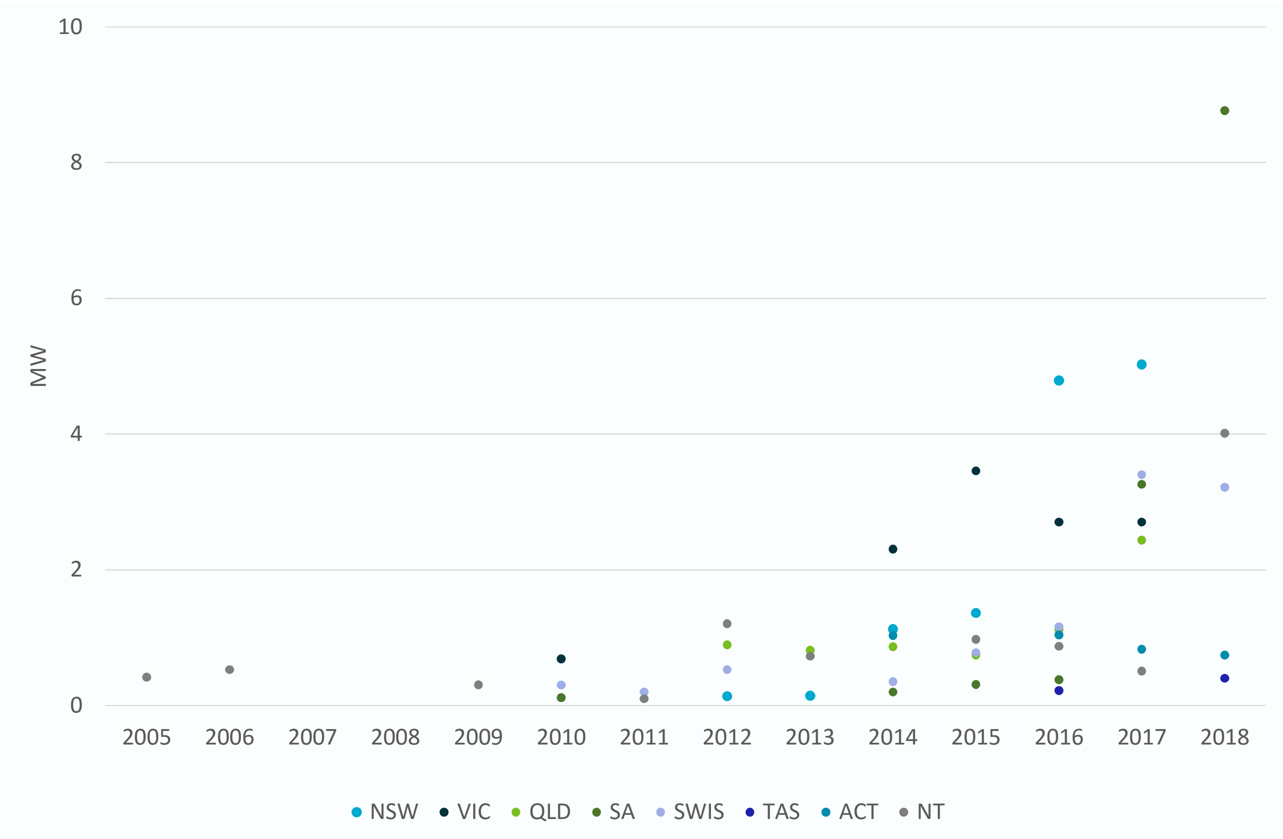


Figure 2-2: Historical deployment by state of solar systems of size 0.1 to 1 MW

Figure 2-3: Historical deployment by state of solar systems of size 1 to 10 MW

Figure 2-4: Historical deployment by state of solar systems of size 10 to 30 MW

2.1.3 Commercial vehicles

It could 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 they offer lower whole of life costs (which also occur sooner than for residential owners because of the longer average driving distances of commercial vehicles). However, we have assumed that infrastructure constraints including the split incentives or landlord-renter problem are also a constraint for businesses noting that many commercial vehicles park at residential premises. For business parked vehicles, if the business doesn't own the building, installing charging infrastructure may not be straight forward. Also, the applicability of range to a business's needs is just as constraining as whether range suits 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. An optional second step is to assign different weights to each factor to reflect their relative importance. Here we outline the factors and weights chosen for the small-scale technology categories.

2.2.1 Weights and factors for rooftop solar and battery storage

Higgins et al (2014) validated prediction of historical sales for rooftop solar by combining a weighted combination of factors such as income, dwelling density and share of Greens voters. While these factors performed well when the model was calibrated for 2010, given the time that has passed and 2010 being very much an early adopter phase of the market we tested a new set of factors. We have also chosen our weights based on data that is readily available in the Statistical Area Level 2 format. The weights and factors applied were tested over 2017 sales data and are shown in Table 2-1.

Battery storage sales data is not available below the state or territory level. Consequently, it is not possible to calculate a set of historically validated combination of weights and factors. In the absence of such data we assume the same weights apply to battery storage as for rooftop solar.

Table 2-1: Weights and factors for residential rooftop solar and battery storage

Factor	Weight
Average income	0.25
Share of separate dwelling households	1
Share of owned or mortgaged households	0.25

The current public data is insufficient to locate commercial systems and slightly distorts our understanding of residential solar capacity per spatial region. The spatial data for solar systems below 100kW is not separated by type of owner, only total installations and kilowatts per postcode. Based on other sources, we know the relative share of residential and commercial systems at a state level. We therefore calculate residential and commercials systems as the state share of systems in that postcode.

2.2.2 Weights and factors for electric vehicles

Previous analysis by Higgins et al (2012) validated a number of demographic factors and weights for Victoria. We apply a similar combination of factors and weights as shown in Table 2-2. These weighting factors provide a guide for the adoption locations, particularly during the early adoption phase which we currently remain in. However, we allow adoption to considerably 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).

Table 2-2: Weights and factors for electric vehicles

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

3 Scenario definitions

The projections for small-scale embedded technologies are provided for the five scenarios as shown in Table 3-1: Neutral, Slow change, Fast change, High DER and Low DER. The AEMO scenario definitions provide useful direction about the differences between the scenarios. In this section we expand on these descriptions to provide greater clarity about what has been assumed in each scenario. We first outline the options for financial and non-financial drivers that are relevant to include in the scenario descriptions. We then combine these more detailed drivers and the original scenario definitions to create extended scenario definitions to support development of modelling assumptions for each scenario.

Table 3-1: AEMO scenario definitions

Demand Settings	Neutral	Slow change	Fast change	High DER	Low DER
Economic growth and population outlook	Neutral	Weak	Strong	Neutral	Neutral
Rooftop PV - up to 100 kilowatts (kW)	Neutral	Proportionally less household installations than the Neutral	Proportionally more household installations than the Neutral	Strong, relatively stronger than “Fast Change”, per capita	Weak, relatively weaker than “Slow Change” per capita
Non-scheduled PV - above 100 kW (up to 30 MW in NEM)	Neutral	Proportionally less commercial installations than the Neutral	Proportionally more commercial installations than the Neutral	Strong, relatively stronger than “Fast Change”, per capita	Weak, relatively weaker than “Slow Change” per capita
Electric vehicle uptake	Neutral	Weak	Strong, with EVs more rapidly reaching cost parity with ICE	Strong, with EVs more rapidly reaching cost parity with ICE	Weak, relatively weaker than “Slow Change” per capita
Electric Vehicle Charging Times	Central Estimate	Slower adoption of consumer energy management opportunities, leading to less controllable charging times	Greater adoption of consumer energy management opportunities, leading to more controllable charging times	Greater adoption of consumer energy management opportunities, leading to more controllable charging	Slower adoption of consumer energy management opportunities, leading to lesser controllable charging
Battery storage installed capacity	Neutral	Proportionally less household installations than the Neutral	Proportionally more household installations than the Neutral	Strong, relatively stronger than “Fast Change”, per capita	Weak, relatively weaker than “Slow Change” per capita
Battery storage aggregation by 2050	Central Estimate	Slower adoption of energy aggregator opportunities, leading to lesser aggregation	Faster adoption of energy aggregator opportunities, leading to more aggregation	Fast, relatively faster than “Fast Change” per capita	Slow, relatively slower than “Slow Change” per capita

Demand Settings	Neutral	Slow change	Fast change	High DER	Low DER
Emissions reduction trajectories	No direct carbon pricing mechanism to signal action to consumers	No direct carbon pricing mechanism to signal action to consumers	No direct carbon pricing mechanism to signal action to consumers, as well as increased policies to support small-scale DER investments, increasing DER uptake	No direct carbon pricing mechanism to signal action to consumers, as well as greatest direct policies to support small-scale DER investments, increasing DER uptake	No direct carbon pricing mechanism to signal action to consumers
Battery cost trajectories (utility and behind the meter)	Neutral	Relatively weaker cost reductions than neutral	Relatively stronger cost reductions than neutral	Relatively stronger cost reductions than neutral	Relatively weaker cost reductions than neutral
Tariff arrangements	No significant change to existing / proposed tariff arrangements.	No significant change to existing / proposed tariff arrangements.	Significant change to existing / proposed tariff arrangements to foster and support a prosumer future, with customers embracing digital trends to take advantage of new tariff structures that lower consumer costs.	Significant change to existing / proposed tariff arrangements to foster and support a prosumer future, with customers embracing digital trends to take advantage of new tariff structures that lower consumer costs.	No significant change to existing / proposed tariff arrangements.

3.1 Financial and non-financial scenario drivers for consideration

3.1.1 Direct economic drivers

Rooftop solar and batteries

Whilst the general buoyancy of the economy is a factor in projecting adoption of small-scale technologies, here we are concerned with the direct financial costs and returns. The key economic drivers which alter the outlook for rooftop solar and battery storage adoption scenarios are:

- any available subsidies or low interest loans (we discuss some government policies further below)
- installed cost of rooftop solar and battery storage systems and any additional components such as advanced metering,
- current and perceived future level of retail electricity prices,
- the structure of retail electricity tariffs or other incentives available to that residence or business,

- the level of feed in tariffs (FiTs) which are paid for exports of rooftop solar electricity,
- wholesale (generation) prices which may influence the future level of FiTs
- the shape of the customer's load curve

Alternative road vehicles

For privately owned electric and fuel cell vehicles the economic drivers are:

- the whole cost of driving an electric or fuel cell vehicle (FCV) including vehicle, retail electricity, the charging terminal (wherever it is installed), hydrogen fuel, insurance, registration and maintenance costs
- the whole cost of driving an internal combustion engine (ICE) vehicle as an alternative including vehicle, fuel, insurance, registration and maintenance costs
- perceptions of future changes in petroleum-derived fuel costs including global oil price volatility and any fuel excise changes
- the structure of retail electricity prices relating to electric vehicle recharging
- the perceived vehicle resale value[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. Electricity derived hydrogen would probably offer 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 a dedicated centralised facilities.

For autonomous private and ride share vehicles the additional economic drivers compared to electric and fuel cell vehicles are:

- the cost of the autonomous driving capability
- the value of avoided driving time
- 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)
- the avoided cost of wages to the transport company for removing drivers from autonomous trucks
- Higher utilisation and fuel efficiency associated with autonomous trucks

[3] While we recognise this driver we don't take any steps to account for it in the modelling due to poor data and complexity. There is no solid data on resale value for electric or fuel cell vehicles as they are in their infancy in Australia. Also, at some point during the transition, poor resale values of newer vehicle types would improve and the resale value conventional vehicles would decline – this dynamic would be scenario specific. Also, some vehicle manufacturers are offering leasing arrangements to overcome customer's resale value concerns.

3.1.2 Infrastructure drivers

Rooftop solar and batteries

One of the key reasons for the already significant adoption of rooftop solar has been its ease of integrating with existing building infrastructure. Battery storage has also been designed to be relatively easily incorporated into existing spaces. However, there are some infrastructure limitations which are relevant over the longer term.

The key infrastructure drivers for rooftop solar and battery systems are:

- The quantity of residential or commercial roof space or vacant adjacent land, of varying orientation, ideally free of shading relative to the customer's energy needs (rooftop solar)
- Garage or indoor space, ideally air conditioned, shaded and ventilated (battery storage)
- The quantity of buildings with appropriate roof and indoor space that are owned or mortgaged by the tenant, with an intention to stay at that location (and who therefore would be able to enjoy the benefits of any longer term payback from solar or integrated solar and storage systems)
- Distribution network constraints imposed on small-scale systems as a result of hosting capacity constraints (e.g. several distribution networks have set rules that new rooftop system sizes may be no larger than 5kW per phase)
- Distribution network constraints relating to connection of solar photovoltaic projects in the 1MW to 30MW range
- The degree to which the NEM and WEM management of security and reliability begins to place limits on the amount of large and small scale variable renewables that can be accepted during peak supply and low demand periods (e.g. to maintain a minimum amount of dispatchable or FCAS serving plant)
- The degree to which solar can be integrated into building structures (flat plate is widely applicable but alternative materials, such as thin film solar, could extend the amount of usable roof space)

Expanding further on the second last dot point, it is not yet clear what mechanisms will be put in place to allow the system to curtail or re-direct rooftop solar exports when state level operational demand drops to near zero levels. There are proposals[4] which allow for greater monitoring and orchestration of consumer energy resources which could include curtailment of rooftop solar but would also seek to shift the charging times of technologies such as batteries and electric vehicles to create additional demand for the required period. The solar forecasts assume that solutions will be put in place to avoid breaching security and reliability limits without putting additional limitations on DER uptake.

[4] See for example the Open Energy Networks project: https://www.energynetworks.com.au/joint-energy-networks-australia-and-australian-energy-market-operator-aemo-project

Alternative road vehicles

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).

In addition, key infrastructure drivers for electric vehicles are:

- 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
- 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.
- Convenient access to highway recharging for owners without access to extended range capability (or other options, see below)
- 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)
- 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

Key infrastructure drivers for fuel cell vehicle are:

- A mature hydrogen production and distribution supply chain for vehicles. 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 fuel cell vehicles 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, we are generally observing a 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 (we define these assumptions 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.

3.1.3 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 3-2 explores some emerging and potential business models which could drive higher adoption.

Table 3-2: Emerging or potential disruptive business models to support embedded technology adoption

Name (technology)	Description	Constraint reduced
Building as retailor **(rooftop solar)**	Apartment or shopping centre building body corporate as retailer	Rooftop solar is more suitable for deployment in dwellings which have a separate roof
Peer-to-peer **(rooftop solar)**	Peer-to-peer selling as an alternative to selling to a retailer	Owners may generate more from solar if they could trade directly with a related entity (e.g. landlords and renters, corporation with multiple buildings, families and neighbours) without a retailer distorting price reconciliation
Solar exports become a network customer obligation **(rooftop solar)**	Networks are incentivised through regulatory changes to purchase voltage management services	Network hosting capacity imposes restrictions on rooftop solar uptake through size of connection constraints and financial impact of curtailment (through inverter tripping, even after accounting for improved inverter standards)
Zero upfront solar **(rooftop solar)**	No money down or zero interest loans for rooftop solar	While costs have fallen, rooftop solar still represents a moderately expensive upfront cost for households and businesses with limited cash flow or debt appetite.
Virtual power plant **(battery storage)**	Retailers, networks or an independent market operator reward demand management through direct payments, alternative tariff structures or direct ownership and operation of battery to reduce costs elsewhere in the system	Given the predominance of volume based tariffs, the main value for customers of battery storage is in reducing rooftop solar exports. The appetite for demand management participation could be more directly targeted than current incentives.
Going off-grid **(Integrated rooftop solar with storage and petroleum fuel generator)**	Standalone power system is delivered at lower cost than new distribution level connections greater than 1km from existing grid	Except for remote area power systems, it is cost effective to connect all other customers to the grid
Going off-grid and green **(Integrated rooftop solar with storage and non-**	Energy service companies sell suburban off-grid solar and battery systems plus a non-petroleum back-	Except for remote area power systems, it is cost effective to connect all other customers to the grid

Name (technology)	Description	Constraint reduced
petroleum fuel solution)	up system yet to be identified but suitable for suburban areas	
Solar/battery new housing packages **(Integrated rooftop solar with storage)**	New housing developments include integrated solar and batteries on new housing as both a branding tool and to reduce distribution network connection costs	Integrated solar and battery systems represent a discretionary and high upfront cost for new home owners under high mortgages
Affordable public charging **(electric vehicles)**	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 period **(electric vehicles and rooftop solar)**	Businesses offer day time 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 which receives low FiTs and is frequently shut off by inverter due to voltage variation in high solar uptake areas
Vehicle battery second life **(electric vehicles and battery storage)**	Electric vehicle batteries are sold as low cost home batteries as a second life application	Battery storage represents a high upfront cost and discretionary investment.
Autonomous ride share vehicles **(electric 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 **(electric vehicles)**	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.	Battery storage represents a high upfront cost and discretionary investment. Using the battery capacity in your electric vehicle for home energy management would be complicated to setup and may void equipment warranties which were designed for isolated operation
Hydrogen economy **(fuel cell vehicles)**	Australia becomes a major hydrogen exporter and this supports some economies of scale in domestic supply of hydrogen for fuel cell vehicles	Fuel cell vehicle distribution infrastructure is not established and will involve a high upfront cost for a business investor.
Collapse of 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 no too much 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.

3.1.4 Commonwealth policy drivers

There are a variety of commonwealth policy drivers which impact solar, battery and electric vehicle adoption. We outline how we have chosen to include them.

Small-scale Renewable Energy Scheme and Large-scale Renewable Energy Target

Rooftop solar currently receives a subsidy under the Small-scale Renewable Energy Scheme whereby rooftop solar is credited with creating small scale technology certificates (STCs) which Renewable Energy Target (RET) liable entities have a legal obligation to buy. Rooftop solar purchases generally surrender their rights to these certificates in return for a lower upfront cost. The amount of STCs accredited is calculated, using a formula that recognises location/climate, based on the renewable electricity generation that will occur over the life of the installation. The amount of STCs accredited to rooftop solar installation will decline over time to reflect the fact that the Renewable Energy Target policy closes in 2030 and therefore renewable electricity generated beyond that time is of no value in the scheme.

STCs can be sold to the Clean Energy Regulator (CER) through the STC Clearing House for $40 each. However, the CER makes no guarantees about how quickly a sale will occur. Consequently most STCs are sold at a small discount directly to liable entities on the STC open market.

The Large-scale Renewable Energy Target (LRET) is a requirement on retailers to purchase large-scale generation certificates (LGCs). This represents a subsidy for large scale renewable generation but is relevant for any solar system above 100kW as they are not eligible for STCs. In this report we are interested in any solar system up to 30MW, hence the price of LGCs is a relevant driver for adoption. The requirements for the LRET are largely met within existing and under construction plant as the target currently plateaus in 2020 and remains at that level until 2030. As a consequence the LGC price is expected to be approaching zero in the next few years.

Potential changes to Commonwealth renewable energy and climate policy

Given Australia's nationally determined commitment at the Paris UNFCCC meeting, there had been growing expectations that some sort of emission credit and targeting policy, with a degree of bi-partisan support, would be implemented to clarify how the electricity sector would contribute to achieving the national greenhouse gas emissions goal. The dissolution of bi-partisan support for this approach makes it more likely that governments will either take no action[5] or use more direct actions such as auctions and lower interest finance of renewable and storage capacity.

Low emission road vehicles policy

Australia is one of the few developed countries without vehicle greenhouse gas emission or fuel economy standards. As a consequence, vehicles sold in Australia are generally 20% less efficient than the same model sold in the UK (CCA 2014). The Commonwealth government has had a process since 2015 for considering a greenhouse gas emission intensity standard for road vehicles.

[5] In its 2018 emission projections process the government pointed out that it might be possible to meet emission reduction targets by crediting excess cumulative emissions reductions achieved in the 2020 period to the 2030 period. In early 2019, it was also announced that funding for the Emission Reduction Fund which sources around 80% of emission credits from the land sector, would be increased. Together, these new approaches imply that little additional abatement would be required from the energy or transport sector

An initial impact study concluded that introduction of a standard would have a positive net benefit on the basis that any increase in vehicle costs to meet the standard is offset by savings in fuel costs over time. The process moved on to designing how such a scheme would work in detail but appears to have stalled. With the changes in approach to achieving the Paris emission targets[6], further progress may be halted altogether although there remains a broad interest in planning for electric vehicles with or without an emissions standard. Low emission vehicles such as electric vehicles are expected to be adopted with or without emission standards but new policies could accelerate their adoption. There is currently no commonwealth fuel excise on electricity or hydrogen used in transport.

3.1.5 State policy drivers

Policies supporting rooftop, larger scale solar and batteries

While subject to potential changes in policy with each election period, it seems likely that Queensland and Victoria will have policies that will work in addition to the Commonwealth RET. Two existing policies are the Victorian Renewable Energy Target (VRET) and Queensland Renewable Energy Target (QRET). Under current auction arrangements VRET is only open to renewable generators above 10MW which is relevant for some small-scale solar but not rooftop solar. However, the current government is providing a subsidy of half the cost of solar (up to a value of $2,225) to 24,000 homes in 2018-19 and announced plans to expand the scheme to zero upfront cost beyond July 2019 for 650,000 homes (with means testing) (Victorian premier, 2018).

The Queensland government accepted a recommendation to not include any incentives under the QRET for rooftop solar in addition to the Commonwealth Small-scale Renewable Energy Scheme. However Queensland does have a zero interest loan scheme for rooftop solar and batteries.

The NSW policy is to provide interest-free loans of up to $9,000 for a rooftop solar and up to $14,000 for solar plus storage through a 10-year Empowering Homes program that will target up to 300,000 households. Eligible households must be owner-occupiers and have an annual household income of up to $180,000 (NSW government, 2019).

There are also a number of state subsidy schemes directly targeting batteries. The South Australia government has a policy of providing subsidies to 40,000 homes to install batteries. The subsidy will be scaled with the size of the battery and capped at $6000. It is being delivered in collaboration with the CEFC. A set of minimum technical requirements for battery systems has been developed to ensure the batteries are capable of being recruited into virtual power plant (VPP) schemes. The Victorian government's Solar Homes policy also includes battery subsidies for up to 10,000 homes (Victorian premier, 2018).

Low emission vehicles

Victoria provides a $100 discount on annual registration fees for electric vehicles. This represents an ongoing subsidy of electric vehicles relative to other vehicle types. Other states offer similar policies including stamp duty discounts. The Australian Capital Territory's policy offers the greatest

[6] See previous footnote

financial incentive. 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.

Feed-in tariffs

Feed-in tariffs (FiTs) were historically provided by most state governments to support rooftop solar adoption but have largely been replaced by voluntary retailer set FiTs for new solar customers. These legacy FiTs are in most cases still being received by those customers who took them up when they were available.

The current FiTs set by retailers recognises some combination of the value of the exported solar electricity to the retailer and the value to the retailer of retaining a rooftop solar customer. Retailer set FITs vary mostly in the range of 7-15 c/kWh across most states. While not calculated directly via this formula, this FiT level is close to the average generation price over a year. While there is retail competition in Northern Territory it is worth noting that FiTs are substantially higher in this region at around 25c/kWh to 30c/kWh reflecting higher costs of generation.

The exceptions, where state government policy or state owned retailers set the feed-in tariff (and are therefore potentially subject to political influence) are as follows:

- **Queensland:** Recognising lower competition, regional Queensland FiTs are set by the state government and were 9.369c/kWh from July 2018.
- **Western Australia:** Only applicable to residential, non-profit and educational premises the Renewable Energy Buyback Scheme pays a FiT of 7.135c/kWh in the SWIS.
- **Victoria:** the current minimum feed-in tariff of 9.9c/kWh is set by the government. It applies to retailers with more than 5000 customers and generation from any renewable energy less than 100kW. The rate will increase to 12c/kWh from July 2019. A time varying feed-in rate is also available from July 2019 with prices between 9.9 and 14.6c/kWh during off-peak and peak respectively and the day time feed-in tariff reduced from 12c/kWh to 11.6c/kWh.
- **Tasmania:** Aurora energy sets the feed-in tariff for residential and commercial customers at 8.541c/kWh from July 2018.

While not binding on retailors, the New South Wales Independent Pricing and Regulatory Tribunal has set a feed-in tariff benchmark price range of 6.9-8.4 c/kWh for 2018-19 and also indicates how the value of solar changes at different times of the day[7].

[7] https://www.ipart.nsw.gov.au/Home/Industries/Energy/Reviews/Electricity/Solar-feed-in-tariffs-201819

3.1.6 Interaction between state and commonwealth policies

Given the divergent policies between the major political parties at the Commonwealth level, the electricity sector could face circumstances where state and Commonwealth policies either complement or double up on each other. In the latter circumstances, there may be a period realignment through the COAG processes to resolve the issues. The net effect of this combined policy space is that support for embedded technologies is not likely to go away completely in the next decade but in a subset of futures energy policy could become more standardised should state and Commonwealth policies converge.

3.1.7 Regulations and standards

Under the current electricity laws the Australian Energy Market Commission (AEMC) can make changes to regulations which are consistent with the goals set out in those laws. There is a general recognition that the electricity market rules were written at a time that did not envisage such a large and competitive role for distributed energy resources. The current customer obligations placed on networks are focussed on reliability of supply and power quality. There is no explicit statement to ensure that customers with rooftop solar can export their excess generation although this does intersect with power quality requirements. If too many rooftop system try to export generation relative to local demand, then voltage rises. Inverters are set to trip off solar exports once voltage exceeds the set point. This then reduces the returns to customers from owning rooftop solar.

Improved inverter standards are somewhat reducing the occurrence of voltage issues associated with high rooftop solar exports onto the local distribution network. Currently installed inverters provide reactive power which limits the impact of exports on voltage. However, if rooftop solar penetration is very high (the exact limit depends on the type of feeder), the improved inverters will be unable to prevent inverter trip off. Also, reactive power uses 20% of the available real power and so still represents an impact on rooftop solar customer returns from lack of distribution network capacity.

Previous projections of operational demand have identified that some state may experience negative load in the 2020s and 2030s if forecasts of rooftop and non-scheduled solar generation projections are realised. This raises the prospect that the electricity system will need to prepare contingencies for demand management or standby generation to maintain system stability.

Given the difficulty of predicting the electricity system reform process and subsequent impacts on customers, we have made no assumptions about the degree of lost solar production and exports as a result of distribution network congestion or efforts to manage state loads for stability.

The current rules are not yet fully clear on regulation of off-grid systems. Although it is becoming clear that customers at the end of long distribution lines could be more reliably and cost effectively served by off-grid systems, customers lose their protections from the electricity laws if they take themselves off-grid. Also, if there is no change to align incentives about who can install, operate and retail off grid systems and who can benefit from cost savings then the adoption rate will be stalled[8]. Current progress is based on trials such as at Western Power[9]. If standalone power systems become widespread they will result in reduced grid demand. Nevertheless, such systems would only represent less than 1% of state consumption in most cases.

Potential changes in regulations to incorporate these new realities associated with distributed energy resources will likely have some impact on the attractiveness (positive or negative) of their adoption. In some cases the rule change process is already in train but is not yet sufficiently mature to infer market impacts.

3.2 Extended scenario definitions

The AEMO scenario definitions have been extended as shown in Table 3-3 by adding additional detail on the economic, infrastructure and business model drivers discussed above with a view to aligning those factors with the original intent of the AEMO scenario definitions. We have not included variations in all drivers in each scenario and some potential changes to policy or business models have been excluded. In that respect, the following assumptions will hold for all scenarios:

- **Cost of long range electric vehicles (LREVs):** Set to be proportionally higher based on additional cost of batteries to achieve 600km range compared to SREV cost assumptions by scenario
- **Feed-in tariffs**: Converges towards (declining) midday wholesale price in all regions
- **Network limits on residential rooftop solar size:** 5kW
- **Business models to overcome upfront costs:** available
- **Off-grid options:** available
- **Solar exports as a network customer obligation:** Not a new rule
- **Vehicle battery second life:** Available from 2040
- **Thin film solar:** No significant uptake[10]

Table 3-3: Extended scenario definitions

Driver:	Neutral	Slow change	Fast change	High DER	Low DER
Economic					
Economic growth and population	Neutral	Weak	Strong	Neutral	Neutral
Cost of solar photovoltaics and battery storage	As per GenCost 2018 report	As per GenCost 2018 report +20%	As per GenCost 2018 report	As per GenCost 2018 report	As per GenCost 2018 report +20%

[8] High cost to serve customers who could be more cost effectively supplied by off-grid systems are not presented with those costs as network costs are socialised across an entire network area and may also be subject to subsidies. Network owners see the costs but are discouraged from owning generation assets or retailing electricity in most states. A current AEMC review is beginning to outline their preferred way of handling these issues.

[9] https://westernpower.com.au/energy-solutions/projects-and-trials/stand-alone-power-systems-trial/

[10] This assumption should not be read to imply that the prospects for this technology are poor. Rather there is not enough data available at this stage to make any meaningful assumptions about its prospects

	Timing of cost[1] parity of short range electric vehicles with ICE	2030	2035	2025	2025	2035
	Cost of fuel cell vehicles	Medium	High	Low	High	Low
	Customers accessing tariffs that support prosumer behaviour and system integration	10% by 2030, 20% by 2050	9% by 2030, 12% thereafter	50% by 2030, 70% by 2050	60% by 2030, 75% by 2050	7.5% by 2030, 10% thereafter
	LGCs or other solar subsidies (e.g. to meet state renewable targets)	$40/MWh falling to near zero by 2021	$40/MWh falling to near zero by 2021	$40/MWh increasing to $50/MWh by 2030, falling thereafter	$40/MWh increasing to $50/MWh by 2030, falling thereafter	$40/MWh falling to near zero by 2021
	Battery storage subsidies	SA up to $6000 for up to 40,000 batteries	SA up to $6000 for up to 40,000 batteries	SA up to $6000 for up to 40,000 batteries	SA policy plus nationally available $2000 subsidy that linearly reduces to zero by 2030[2]	SA up to $6000 for up to 40,000 batteries
Infrastructure						
	Growth in apartment share of dwellings	Medium	High	Low	Low	High
	Decline in home ownership	Medium	High	Low	Low	High
	Extent of access to variety of charging options	Medium	Low	High	High	Low
Business model						
	Tariff and DER incentive arrangements	No significant change	No significant change	Significant change.	Significant change	No significant change
	System architecture changes support greater incentives to DER participation	Medium	Low	High	High	Low
	Feasibility of vehicle to home storage	Low	Low	Medium	High	Low
	Feasibility of ride sharing services	Medium	Low	High	High	Low
	Feasibility of participation of apartment dwellers and renters in DER	Low	Low	High	High	Low
	Affordable public charging availability	Medium	Low	High	High	Low
	Vehicle to home	No	No	No	Yes from 2040	No
	Hydrogen export industry supports hydrogen fuel supply	No	No	Yes	No	No

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

2. This subsidy proxies the general combined roll out of state policies which are in reality more varied in their design but for simplicity are assumed to converge to something similar to this level of support.

The scenario definitions are in some cases described here in general terms such as “high” or “Low”. Specific scenario data assumptions are outlined in the next section.

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 Solar photovoltaic panels and installation

The costs of installed rooftop or small scale solar installations for each scenario is shown in Figure 4-1 and is sourced from the 4 degrees[11] scenario in the GenCost 2018 report by Graham at al. (2018) which is the most recent public Australian technology costs projections report available. The Neutral scenario is assigned this cost assumption. The Slow change and Low DER scenarios are assumed to have 20% higher costs by 2030 converging back towards a common level by 2050. Conversely, the Fast Change and High DER scenarios are assumed to have 20% lower costs but also converge by 2050.

Note that 2019 costs shown imply that a 3kW system ought to be advertised for approximately $5100. However, we more commonly see systems advertised in the range of $3600 installed reflecting that the value of small scale certificates, which are around $450-550/kW depending on the location. They have been subtracted from the price with the intent that owners will give up their rights to claim them to the installer in return for a discount on the upfront cost. Another feature of the market is that larger systems have economies of scale such that costs for a 5kW system maybe discounted by $100-200/kW.

It is also evident that locations that are further from capital cities pay a remoteness premium for installations and we have factored this in as a one third premium. A full survey of regional market prices was not in scope.

[11] The difference between the 4 degrees and 2 degrees scenarios is not large and 4 degrees is the most consistent with current nationally determined commitments by countries.

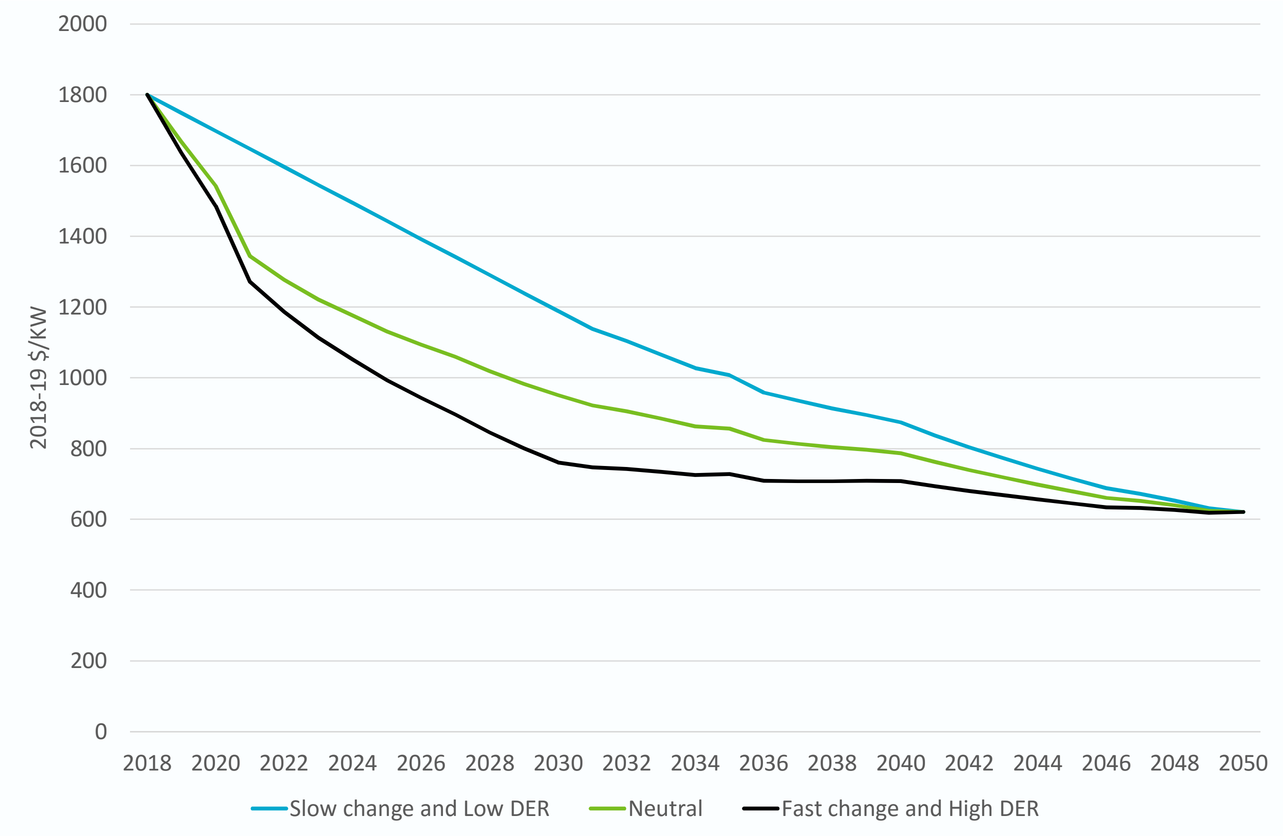


Figure 4-1: Assumed capital costs for rooftop and small-scale solar installations by scenario (excluding STCs or other subsidies)

4.1.2 Batteries and installation

The Neutral scenario battery and balance of plant costs are assumed to align with GenCost 2018 projections and are shown in Figure 4-2[12]. These are upfront costs and do not take account of degradation or cost of disposal at end of life. GenCost 2018 projects a continued non-linear reduction in batteries and a close to linear reduction in balance of plant costs during the 2020s after which cost reductions slow. Inverters are the largest balance of plant cost. Other elements of balance of system are system integration and installation. The Slow change and Low DER scenario battery and balance of plant costs are assumed to be 20% higher and Fast change and High DER scenario costs are 20% lower.

[12] This data relates directly to commercial scale batteries but provides a better picture of the battery pack and balance of plant breakdown. GenCost 2018 provides a specific solar plus integrated battery projection which is more relevant to smaller scale but includes solar costs.

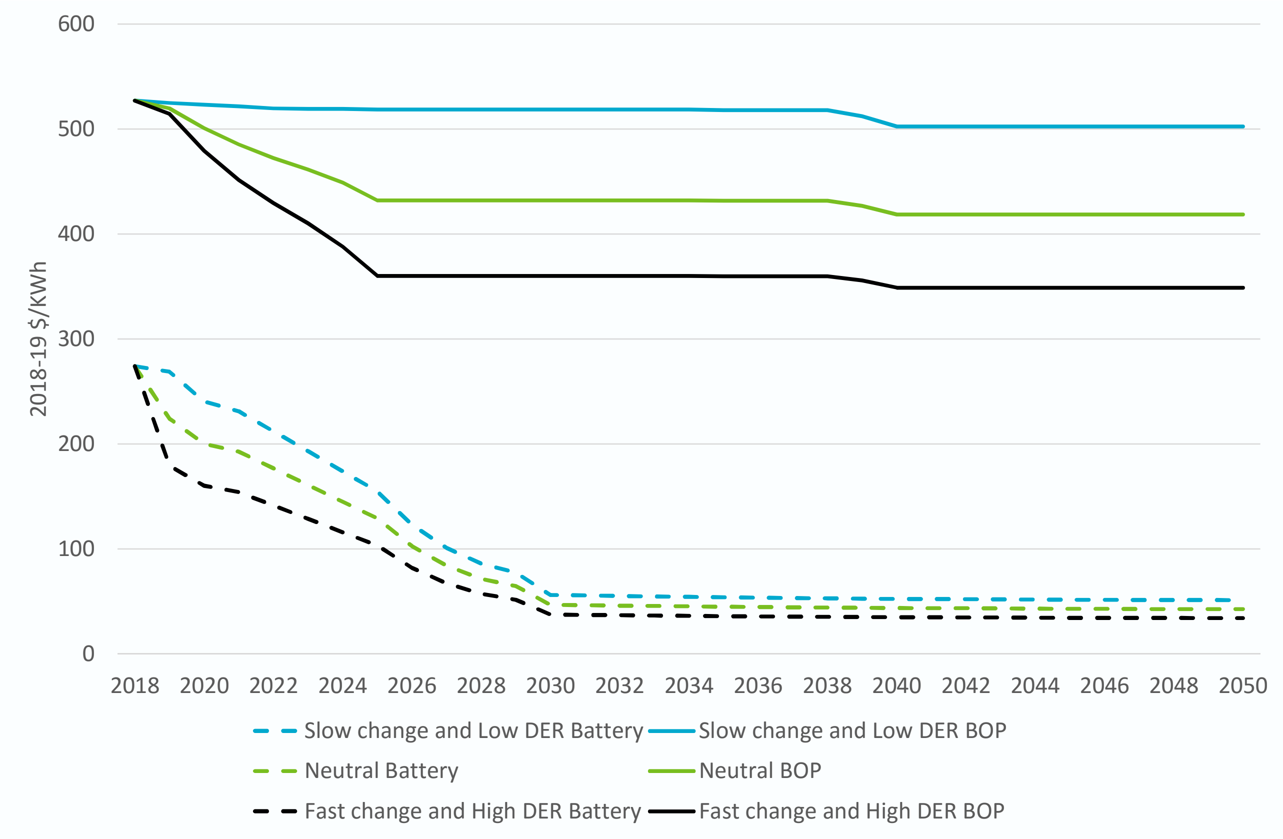


Figure 4-2: Assumed capital costs for battery storage installations by scenario

4.1.3 Electric and fuel cell vehicles

Neutral scenario short range electric vehicle (SREV) costs are assumed to reach upfront cost of vehicle parity with internal combustion engine light vehicles around 2030 and remain at that level thereafter (Table 4-1). Heavy SREVS are assumed to reach parity ten years later due to their delayed development relative to light vehicles and higher duty requirements (both load and distance). Parity may be reached earlier in other countries where vehicle emissions standards are expected to increase the cost of internal combustion vehicles over time[13].

We consider 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. The costs of LREVs do not reach vehicle cost parity because their extra range adds around $5000 in battery costs to light vehicles (and proportionally more to heavy vehicles). However, from a total cost of driving perspective (i.e. $/km), they are still lower cost over their life, paying back the additional upfront cost through fuel savings within 2-3 years.

We do 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 pay back with limited additional fuel savings.

[13] There is currently a process in Australia to consider policy design options for vehicle emission standards in Australia. However, no firm legislative proposal has emerged as yet. See https://infrastructure.gov.au/vehicles/environment/emission/index.aspx

Table 4-1: Moderate scenario internal combustion and electric vehicle cost assumptions, real 2019 $'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

The Slow change, Fast change, High DER and Low DER scenario assumptions are framed relative to these neutral scenario assumptions. In the Slow change and Low DER scenario we assume that the cost reductions are delayed by 5 years. In the Fast change and High DER scenario we assume the cost reductions are brought forward by 5 years. Fuel cells are an exception. It is assumed they have an accelerated cost reduction in Low DER as an additional driver for lower adoption of electric vehicles in that scenario (i.e. via increased competition).

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, we considered 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).

4.1.4 Autonomous vehicle costs and value

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 fairly 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 we value 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) use a value of 20% for the AV cost premium which would be $3,000 to $8,200 for the standard vehicle types used in our modelling. We interpret their costing approach to be focussed on a larger vehicle and longer term point of view. This matches the expectation that the first autonomous vehicles would likely be towards the larger less-budget conscious end of the market.

Based on these studies we assume AVs have a premium starting at $10,000 from 2020 decreasing to $7,500 by 2030 and remaining at that level. Given how consumers value time, significant cost reductions won't be necessary to support growth in adoption. However, we assume 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 and in doing so avoiding the costs of driver's wages 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. However, if these vehicles are able to achieve full autonomy, the avoided wages costs are a significant financial incentive.

4.2 Electricity prices

4.2.1 Retail and generation prices

Broadly speaking electricity generation prices are expected to fall in the next few years as a major expansion in renewable generation capacity is delivered. However, over the long term, prices are expected to rise again due to retirement of plant with low marginal costs (i.e. sunk capital) and the need to incorporate more balancing technologies such as storage as variable renewable shares approach 50%. Offsetting this is the long term decline in costs of variable renewables so price increases are expected to be modest.

Assumed changes in residential retail prices under all scenarios follow this assumed falling and then slightly increasing trend. 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 as we discuss below.

4.2.2 Small-scale technology certificates (STCs)

While there is the option to sell to the STC Clearing House for $40/MWh, the value of STCs is largely determined on the open market and vary according to demand and supply for certificates. The amount of certificates generated depends roughly on the solar capacity factor in different states although this calculation is not spatially detailed (i.e. involves some significant averaging across large areas). Solar generation is calculated over the lifetime, but any life beyond 2030 is not counted as it is beyond the scheme period. Therefore over time the eligible solar generation is declining. Multiplying the eligible rooftop solar generation by the STC price gives the projected STC subsidy by state shown in Figure 4-3.

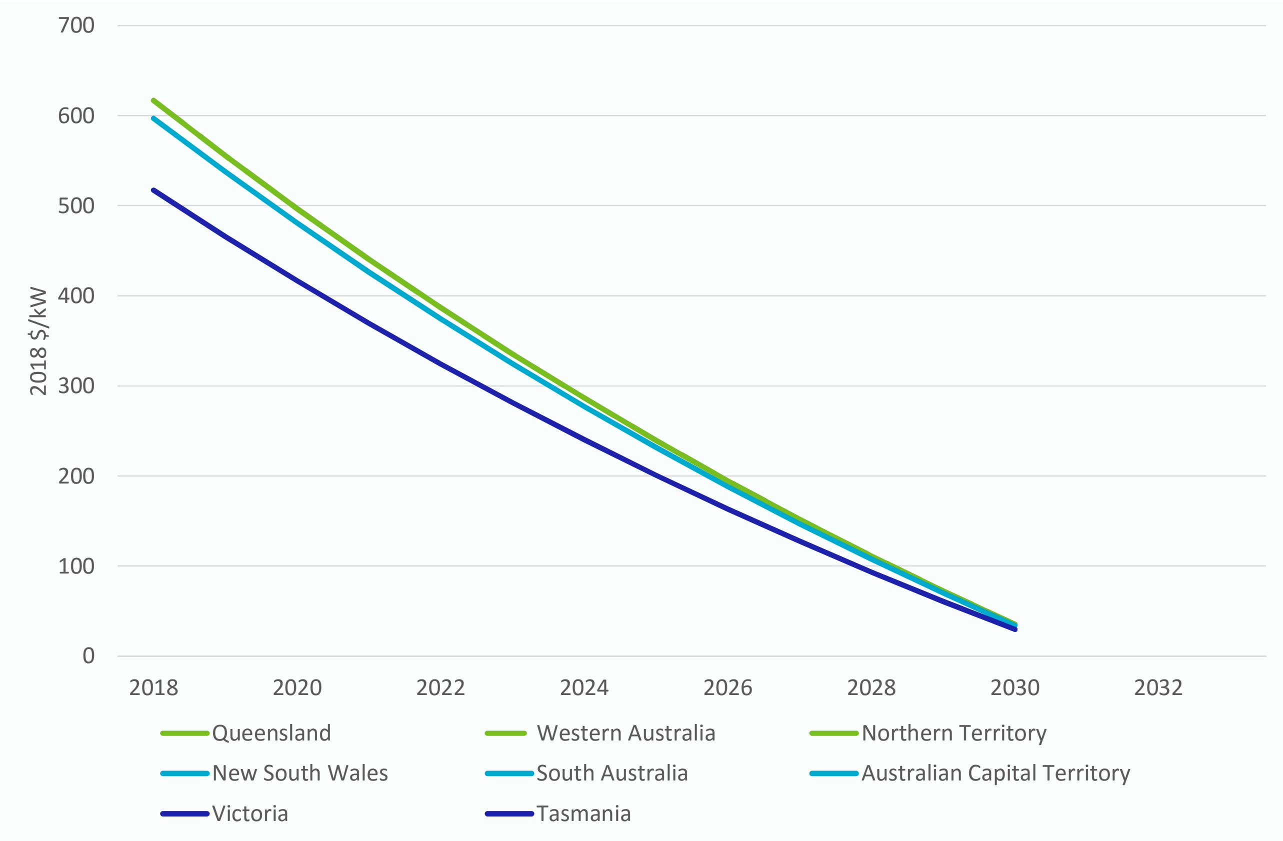


Figure 4-3: Assumed STC subsidy available to rooftop solar and small scale solar systems by state

4.3 Electricity tariff structures

4.3.1 Current status

Electricity tariff structures are important in determining the return on investment from customer adoption of small-scale embedded technologies 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 we will call 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.

4.3.2 Future developments

While retailers make business-like TOU and demand tariff structures available to residential customers in addition to flat tariffs, their adoption is very low[14]. 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.

There are no current policies which would force residential customers to adopt alternative tariff structures. As such one could consider the prospects for greater residential adoption are considered low without a change in policy. Moving to these alternative residential tariff structures inherently requires customers to be more aware and, if concerned, manage on a daily basis their electricity use. Battery storage with automated operating instructions offers customers a way to adopt new tariffs without having to actively manage their daily load. In fact, new energy service companies already act as a customer's agent in managing the battery storage operation, minimising their power bill under TOU or demand tariff structures, with the ability to offer demand management services to both networks and the wholesale market.

---

[14] There is a significant body of literature examining why this is the case which we will not review here. See, for example, Stenner et al. (2015).

4.3.3 Assumed smart tariff structures

The consideration of potential developments in residential tariffs discussed above is why we have adopted alternative assumptions for the rate of adoption of smart tariffs in Table 3-3. However, to implement these scenarios we need to assume a specific smart tariff structure in each year of the projection period. For TOU tariffs, this is a difficult task because the time of day when certain rates might apply will shift with the change in customer behaviour. For example, greater adoption of rooftop solar and electric vehicles could mean low rates for night time power usage are no longer appropriate. Demand tariffs which are structured to reduce demand during the evening peak could be constructed over time by assuming they continue to draw the same ratio of revenue from their volume ($/kWh) and demand ($/kW) components.

Most studies of battery behaviour under either TOU or demand tariffs conclude that these tariffs will drive coincident battery owner behaviour around the start and end of the time defined demand or usage periods. While it might be effective in reducing peak demand, it undermines the key purpose of the smart tariffs to increase diversity of demand across the day. It replaces a peak demand problem with an edge of peak demand problem that might be worse than the peak demand problem if the scale of installed batteries is large enough.

The system could persist with offering demand and TOU tariffs to battery owners for several years but as adoption increases it will need to offer alternative approaches to battery control. Given the large number of potential batteries to coordinate the most direct route would be for battery owners to pass control of the battery to an aggregator who can learn by experience the value of demand response to the system and reward its battery-owning participants accordingly. The value of that demand response is already partially defined by the premium of price during peak periods in each state. It could also be defined by the lowest bill a battery owner could achieve from participation in conventional retail tariffs. That is, an aggregator ought to be able to lure customers to the aggregation scheme so long as it can offer to improve or match their current best bill outcome. This annual rebate that an aggregator would need to offer was calculated as an intermediate model output to be in the range of $100-400 per annum depending on the state and customer size.

For commercial customers who were already on some type of peak demand avoidance tariffs, the premium they could be paid for adjusting their load would be smaller. Also note that, since commercial load profiles have a closer match to solar output profiles and are more amenable to avoiding peaks, they will have significantly less incentive to take up battery storage. This situation differs in the SWIS where, if customers can reduce their demand over the peak intervals used to calculate their individual reserve capacity requirement (IRCR) obligation, they could save up to $200 per kW of reduced load.

4.3.4 Implications of tariffs and incentives for battery operating regimes

Under flat tariffs customers will set their battery to do two things:

- If solar exports are detected and the battery is not full, charge
- If electricity imports are detected and the battery is not empty, discharge

This is a relatively simple onsite algorithm to implement and generally comes as part of the battery manufacturer's standard settings at present.

Under a demand or TOU tariff an onsite algorithm can be tuned to avoid grid imports during the peak demand/pricing period. Apart from shifting any solar power output, this could involve charging the battery from the grid at low price periods (under TOU) and also charging the battery just before the peak period (TOU or demand tariff structure). This behaviour would be more likely on low solar output days and for systems where the size of the solar system is smaller relative to consumption. A battery provider or an energy service company might be employed to continuously tune the battery regime since retailer pricing structures change over time requiring updating of the optimal strategy.

Under virtual power plant (VPP) arrangements an aggregator controls the battery to meet the demands of an independent system operator (called the distribution system operator (DSO) when distribution system located resources are managed to achieve outcomes aligned with the local distribution network). Such arrangements do not yet exist but are in the early planning stages[15]. In VPP mode, the battery is given over to the single objective of meeting the generation sector's needs but may return to the default mode of shifting solar power on site when not called upon. The battery can potentially be discharged to its fullest if deemed useful for the system and if the reward for the customer is greater than that from responding to onsite needs.

Table 4-2: Assumed proportions of battery storage operating regimes across residential customers

Year	Battery operation regimes	Shift solar	Shift solar and avoid peak	Virtual power plant
	Tariff / incentive	Flat	TOU / demand	Rebate / discounted bill
	Control	Onsite algorithm	Onsite algorithm	Aggregator / distribution system operator
2030	Neutral	90%	6%	4%
	Slow change	91%	5%	4%
	Fast change	50%	30%	20%
	High DER	40%	36%	24%
	Low DER	93%	5%	3%
2050	Neutral	80%	2%	18%
	Slow change	88%	1%	11%
	Fast change	30%	7%	63%
	High DER	25%	8%	68%
	Low DER	90%	1%	9%

The assumed long term shares of the adoption of alternative battery operation regimes reflects the current types of tariffs faced by residential and commercial customers and the assumed progression of the scenario towards adoption of tariffs and incentives that support the broader electricity system's needs. While the pathways for states will differ due to different starting points,

[15] https://www.energynetworks.com.au/open-energy-networks-consultation-paper

we are effectively assuming a convergence in incentives by holding long term assumptions to be the same in each state.

Table 4-3: Assumed proportions of battery storage operating regimes across commercial customers

Year	Battery operation regimes	Shift solar	Shift solar and avoid peak	Virtual power plant
	Tariff / incentive	Flat	TOU / demand	Rebate / discounted bill
	Control	Onsite algorithm	Onsite algorithm	Aggregator / distribution system operator
2030	Neutral	18%	72%	10%
	Slow change	17%	68%	15%
	Fast change	10%	40%	50%
	High DER	8%	32%	60%
	Low DER	19%	74%	8%
2050	Neutral	8%	72%	20%
	Slow change	9%	79%	12%
	Fast change	3%	27%	70%
	High DER	3%	23%	75%
	Low DER	9%	81%	10%

4.4 Income and customer growth

4.4.1 Gross state product

Gross state product (GSP) assumptions by scenario are presented in Table 4-4. These assumptions are used to project commercial vehicle numbers and are relevant for calibrating adoption functions where income is part of the adoption readiness score.

Table 4-4: Annual percentage growth in GSP by state and scenario

	New South Wales	Victoria	Queensland	South Australia	Western Australia	Tasmania	Australian Capital Territory	Northern Territory
Slow	1.3	1.6	2.5	1.5	2.5	1.0	2.1	2.7
Moderate	2.2	2.6	3.3	2.2	3.2	1.8	3.0	3.2
Fast	3.0	3.4	4.0	2.9	3.9	2.5	3.7	3.7

4.4.2 Customers

Customer growth assumptions by scenario are shown in Table 4-5. These assumptions are relevant for establishing the current market share of solar and battery customers and converting projected adoption shares back to number of installations.

Table 4-5: Annual percentage rate of growth in customers by state and scenario

	New South Wales	Victoria	Queensland	South Australia	Western Australia	Tasmania	Australian Capital Territory	Northern Territory
Slow change, Low DER	0.9	1.1	1.3	0.6	2.0	0.2	1.2	0.5
Neutral	1.0	1.3	1.5	0.7	2.2	0.3	1.5	0.5
Fast change, High DER	1.1	1.5	1.7	0.8	2.4	0.4	1.7	0.6

4.5 Separate dwellings and home ownership

4.5.1 Separate dwellings

Owing to rising land costs in our large cities where most residential customers live, there has been a trend towards faster building of apartments compared to detached houses (also referred to as separate dwellings in housing statistics). As a result we expect the share of separate dwellings to fall over time in all scenarios. The assumptions for the neutral scenario were built in extrapolating past trends resulting in separate dwellings occupying a share of just below 60% by 2050, around 6 percentage points lower than today. The Slow change, Low DER, Fast change and High DER scenario assumptions were developed around that central projection.

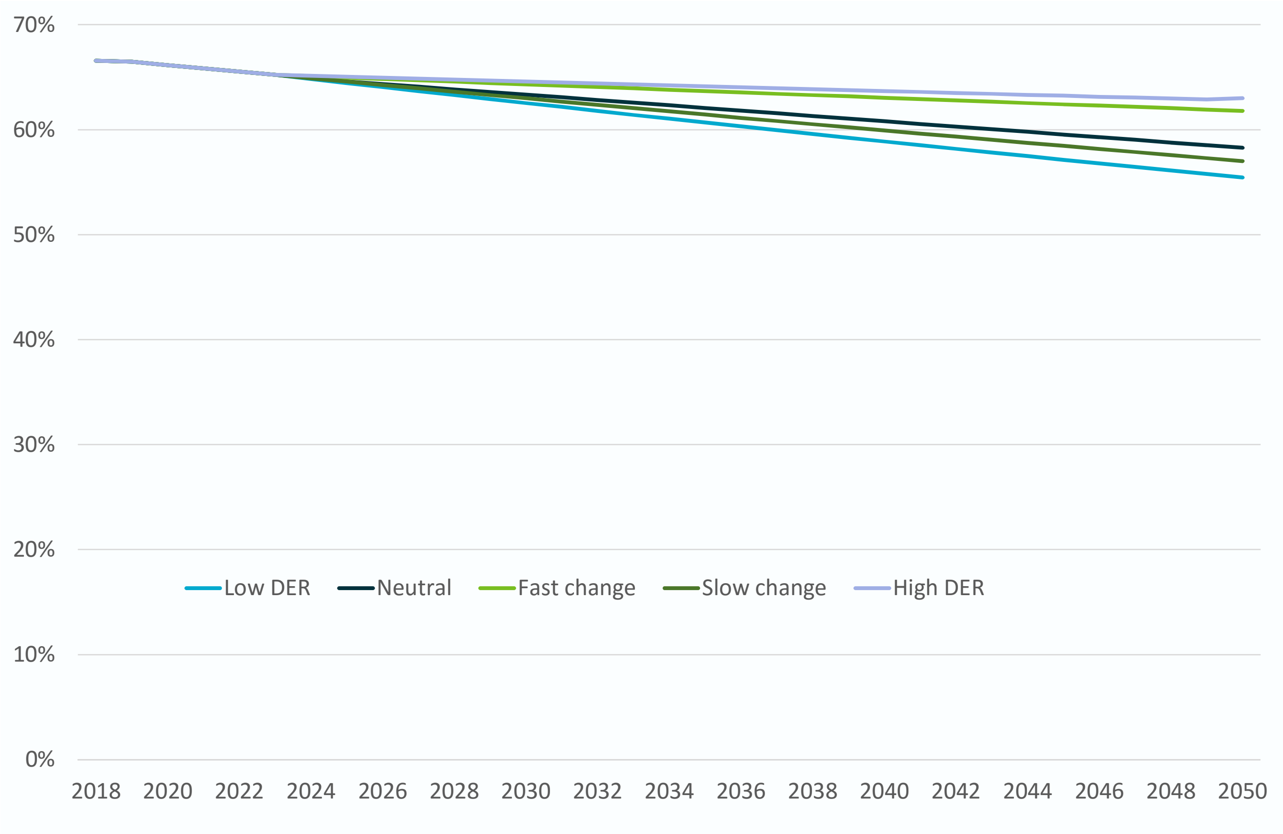


Figure 4-4: Assumed share of separate dwellings in total dwelling stock by scenario

4.5.2 Home ownership

While not a hard constraint, home ownership increases the ability of occupants to modify their house to include small-scale embedded technologies. Home ownership (which includes homes owned outright as well as mortgaged) increased rapidly post-World War II and was steady at around 70 percent for the remainder of last century. However, in the last 15 years ABS Census data as reported by AIHW (2017) shows that home ownership has been declining and was an average 65.5% in 2016 with the largest declines amongst young people (25 to 34), although all ages below 65 experienced a consistent decline between Censuses.

In the long run we might expect the housing market to respond by providing more affordable home ownership opportunities. However, we must also acknowledge that 15 years represents a persistent trend. As such, under the Neutral scenario, we assume the trend continues and we apply the rate of decline in the last 15 years to the year 2050. Under the Slow change and Low DER scenarios we assume the slightly faster trend of the last 5 years prevails, leading to a slightly faster reduction in home ownership rates relative to the neutral scenario. Under the Fast change and High DER scenarios we assumed a slower rate of decline in home ownership consistent with the trend of the last 25 years representing a slowing in the rate of decline relative to recent history.

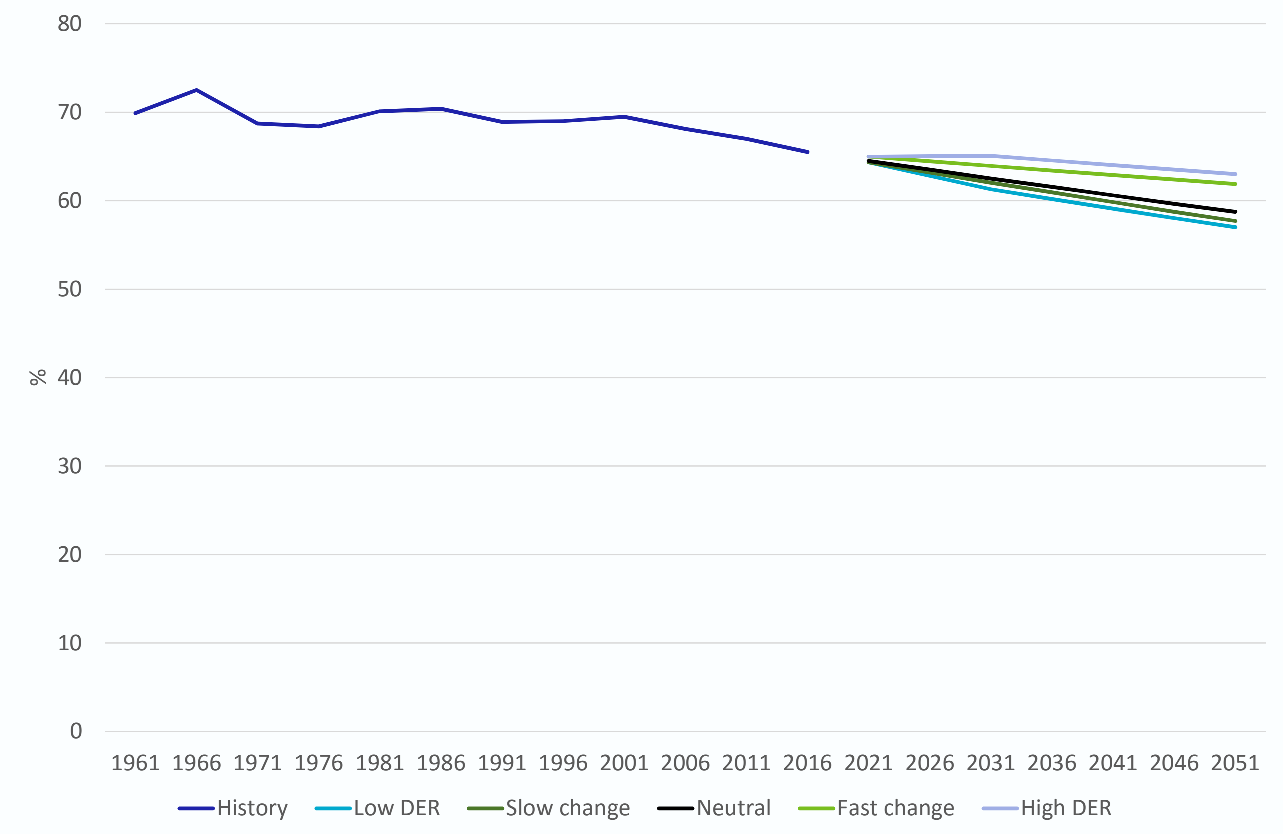


Figure 4-5: Historical (ABS Census) and projected share of homes owned outright or mortgaged, source AIHW (2017)

4.6 Vehicle market segmentation

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

In Table 4-6 we list eight non-financial factors that might limit the size of a vehicle market segment. These are generally based around limits faced by households because the relevant data for households is easier to access. However, we argue that many of the limitations apply equally to businesses, or, if not there is an equivalent concept (see the last column). Each row describes the share of households in that 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 used to calibrate the consumer technology adoption curve saturation rates such that the indicated rate of sales will apply once the vehicle has reached a low payback period (i.e. once financial constraints are no longer an issue), whenever that may occur.

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 4-6: Non-financial limitations on electric and fuel cell vehicle uptake and the calculated maximum market share

		Neutral	Slow change	Fast change	High DER	Low DER	Rationale/formula	Equivalent business constraint
Limiting factors (residential)								
Separate dwelling share of households	A	58%	57%	62%	63%	55%	Based on housing industry forecasts	Businesses located on standalone site
Share of home owners	B	59%	58%	62%	63%	57%	Based on historical trends	Business not renting their site
Share of landlords who enable (passively or actively) EV charging onsite	C	50%	25%	75%	80%	20%	Data not available. Assumed range of 20-80%	Same
Off-street parking/private charging availability	D	37%	31%	45%	47%	29%	Assume 80% of separate dwellings have off-street parking. Formula=(0.8*A*B)+(0.8*A*(1-B)*C)	Same
Public charging availability	E	30%	25%	45%	50%	20%	Availability here means at your work/regular daytime parking area 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%	62%	65%	55%	Based on historical trends	Share of businesses with two or more fleet vehicles
Share of houses where second vehicle is available for long range trips	G	70%	67%	72%	75%	65%	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/FCV costs or features	H	20%	25%	10%	5%	30%	Based on laggards generally being no larger than a third of customers. High DER assumes ICEs suffer a collapse in manufacturing due to systematic loss of supporting infrastructure	Business owner's attitudes and specific vehicle needs
Share of people who prefer private vehicle ownership for all household cars	I	20%	25%	10%	5%	30%	As above with High DER assuming a collapse in 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	80%	75%	90%	95%	70%	Assumed that only a laggard proportion would object to this arrangement	Same
Fuel stations with access to hydrogen supply chain	K	13%	5%	20%	15%	8%	Data not available due to uncertainty. Assume range of 5-20%. Fast change assumes supply chain is boosted by hydrogen export industry	Same
Maximum market share								
Short range electric vehicles		14%	10%	19%	23%	8%	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)	
Long range electric vehicles		54%	42%	81%	92%	34%	Key limitation is charging and customers who would prefer ICE. Formula=(1-H)*(D+E)	
Plug-in hybrid electric vehicles		54%	42%	81%	92%	34%	*Same as long range*	
Fuel cell vehicles		10%	4%	18%	14%	5%	Formula=(1-H)*K	
Autonomous ride share vehicles		56%	54%	60%	64%	52%	Formula=J*F+(1-F)*I	

Table 4-7: Shares of different electric vehicle charging behaviours by 2050 based on limiting factor analysis

		Neutral	Slow change	Fast change	High DER	Low DER	Rationale/formula
Limiting factor							
Customers accessing tariffs that support prosumer behaviour and system integration	L	20%	15%	70%	75%	10%	Scenario assumption
Residential vehicles							
Home charging convenience profile		30%	26%	13%	6%	26%	Formula=(1-L)*D or (1-L)*D*(1-E) for High DER scenario to account for vehicle to home group
Home charging night/off peak aligned		7%	5%	31%	18%	3%	Formula=L*D or L*D*(1-E) for High DER scenario to account for vehicle to home group
Vehicle to home charging pattern (day time public charge, provide all household consumption while at home)		0%	0%	0%	23%	0%	Vehicle to home is only assumed in High DER scenario. Other relevant constraints are public charging and off-street parking to connect to home. Formula=D*E
Public charging highway fast charge		5%	5%	5%	5%	5%	90%+ of driving is within 30km of home
Public charging solar aligned		58%	64%	50%	48%	66%	Residual
Commercial vehicles							
Light commercial							
LCV - Daytime convenience		76%	85%	30%	25%	90%	Non-highway kilometres. Formula=(1-L)*0.95
LCV - Daytime adjusted for solar alignment		19%	15%	70%	75%	10%	Non-highway kilometres. Formula=L*0.95
LCV highway fast charge		5%	5%	5%	5%	5%	Assume similar pattern to residential driving

Trucks & buses morning peak convenience	76%	81%	29%	24%	86%	Non-highway kilometres. Formula=(1-L)*0.95
Trucks & buses solar aligned	19%	14%	67%	71%	10%	Non-highway kilometres. Formula=L*0.95
Trucks & buses highway fast charge	5%	5%	5%	5%	5%	Assume similar pattern to residential driving

4.7 After life electric vehicle batteries and vehicle to home

Once electric vehicles are established 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 ten times larger than the average 10kWh 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.

We rule out using electric vehicle batteries after their on-vehicle life. Such a scheme would only make sense if electric vehicles frequently replaced their batteries well before their expected shelf lives of 10 years[16]. That is, they reach the end of their cycle life before their shelf life expires. The end of cycle life is where the battery degrades to 70-80% of its rated capacity and lithium ion batteries are typically rated at around 5000 cycles where a cycle is full charge-discharge (down to 5% and up to last 5% capacity). The average vehicle in Australia travels 11,000km per year. For an SREV vehicle 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%. Even 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 more 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 from 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[17].

---

16 "Shelf life" is used here as a proxy for all other life reducing impacts other than cycle life such as ambient temperature, pressure, venting and loss of electrolyte. See Cavanagh et al (2015)

17 https://www.nissan-global.com/EN/TECHNOLOGY/OVERVIEW/vehicle_to_home.html

4.8 Shares of electric vehicle charging behaviour

Besides informing the technology adoption, the maximum market shares identified in Table 4-6 are also used, together with other assumptions, to determine what shares of different electric vehicle charging profiles should be applied by 2050 (Table 4-7). The key additional assumption is to assign the percentage of customers that are participating in tariffs or other incentives which support prosumer and electricity system supporting behaviour (which is a scenario assumption).

For residential vehicles we assume a small amount of highway charging consistent with the observation from many trip studies that around 90% of driving is within local areas (see, for example, BITRE 2015). The amount of home charging is calculated from the amount of off-street parking (calculated in Table 4-6). Charging at home is split between convenience and solar aligned charging based on the tariff and other incentives assumptions. The formula for High DER is modified to allow for a number of customers to run their home off their vehicles 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 already reasonably well aligned to the daytime but could be even more aligned with solar generation to support the electricity system. Current tariffs faced by the commercial sector may also incentivise avoiding peak periods. We assume that signing up to new tariffs or incentives would imply shifting that part of daytime charging which is not aligned with solar generation times into that time.

4.9 Automated vehicles and vehicle fleet size

As part of the modelling phase we have projected the uptake of automated vehicles in both the light and heavy vehicle markets for private use and as ride share vehicles. The main delay in adopting these technologies is achieving full safety and technology feasibility. Otherwise the benefits in terms 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 on adoption over time across the scenarios based on general uncertainty around this new way of delivering road transport services.

Figure 4-6 shows the projected share of passenger and freight autonomous vehicles by scenario. The total across both vehicle types ranges in the scenarios from 10% to 35% by 2050. Passenger vehicles are disaggregated further into private and ride share vehicles in Figure 4-7. Rideshare vehicles are of particular interest to this study because they could reduce the number of vehicles required. The share of rideshare vehicles increases from around 1% by 2050 in the Slow change and Low DER scenarios to up to 6% in the Fast change and High DER scenarios. While these percentages are small, each rideshare vehicle may displace another 2 to 3 vehicles depending on how successful they are in concentrating passengers into the rideshare vehicle.

The impact of these assumptions is that the projected growth in the number of vehicles declines from historical rates after 2030 and increasingly so in the Neutral, Fast change and High DER scenarios (Figure 4-8).

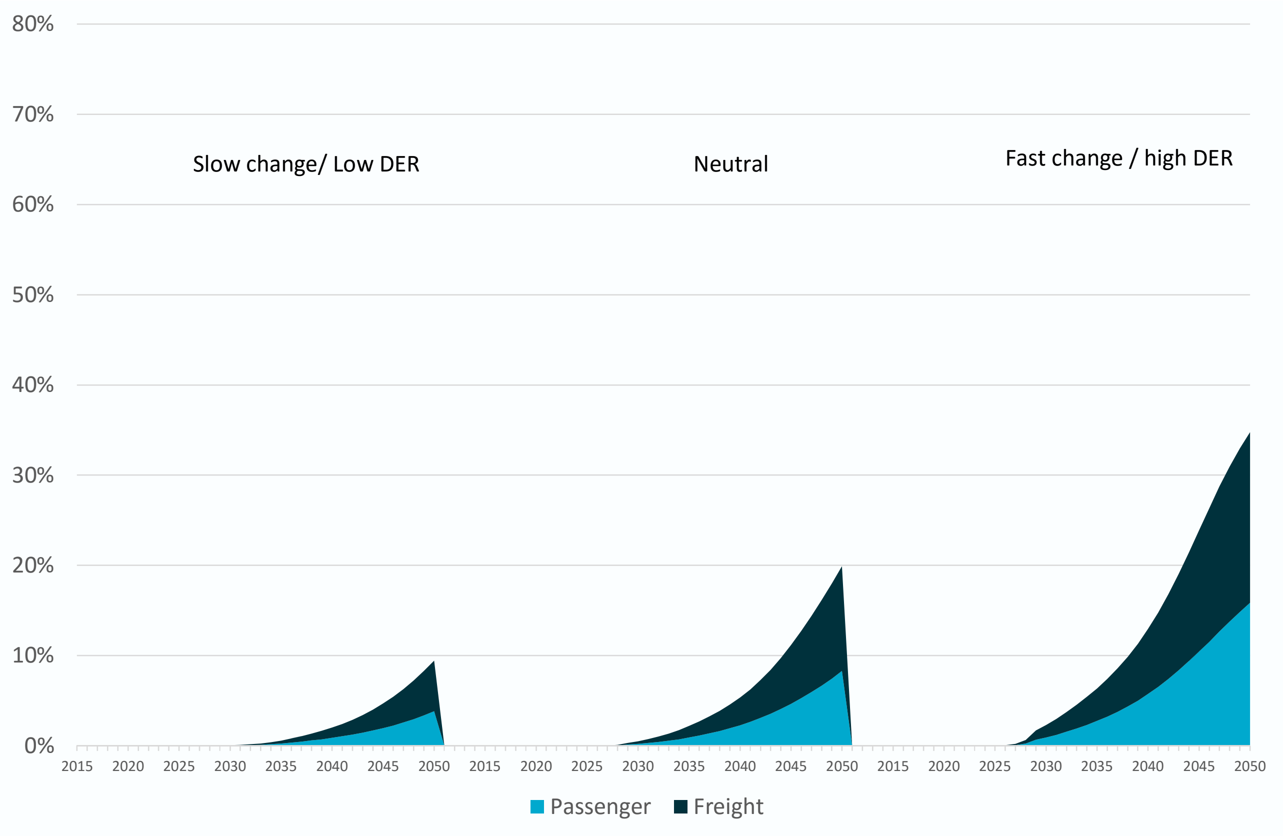


Figure 4-6: Share of passenger and freight autonomous vehicles in the road vehicle fleet by scenario

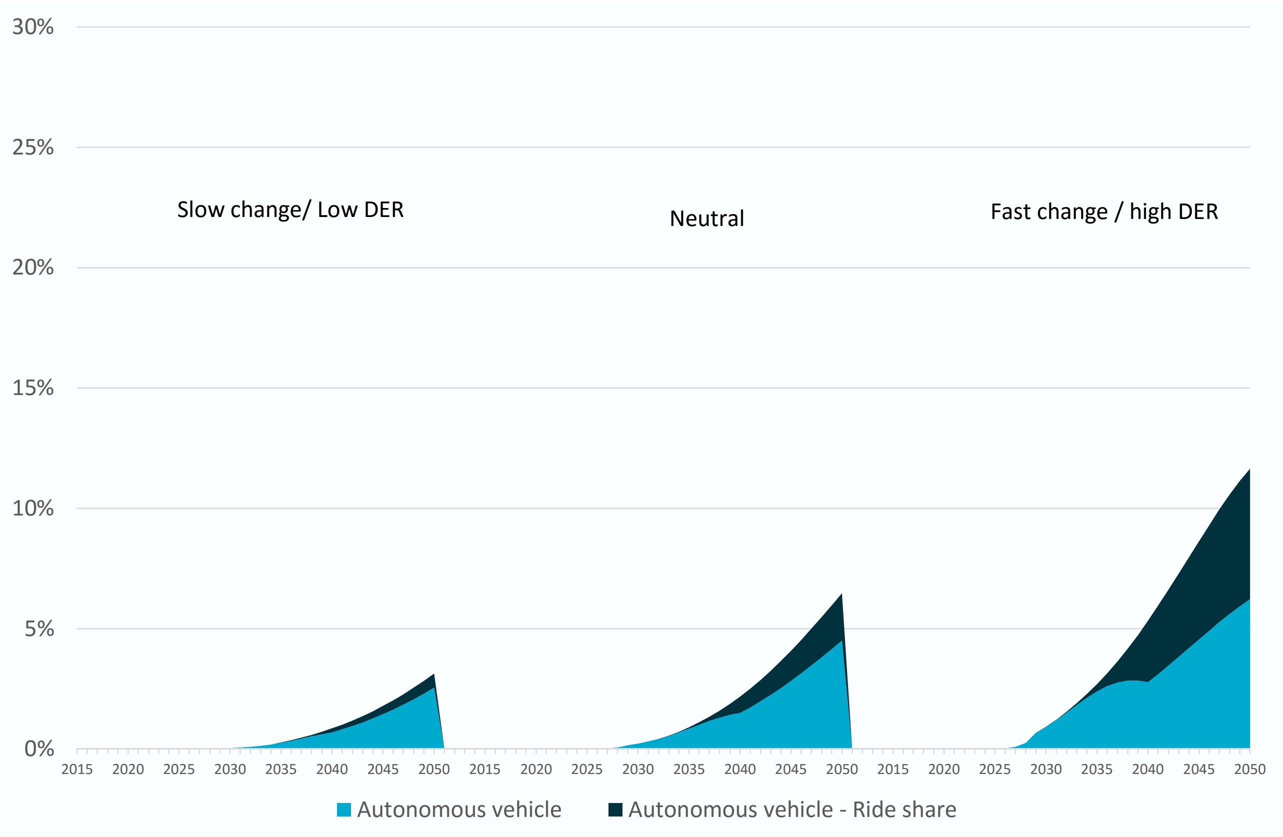


Figure 4-7: Share of passenger autonomous vehicles by private or ride share types by scenario

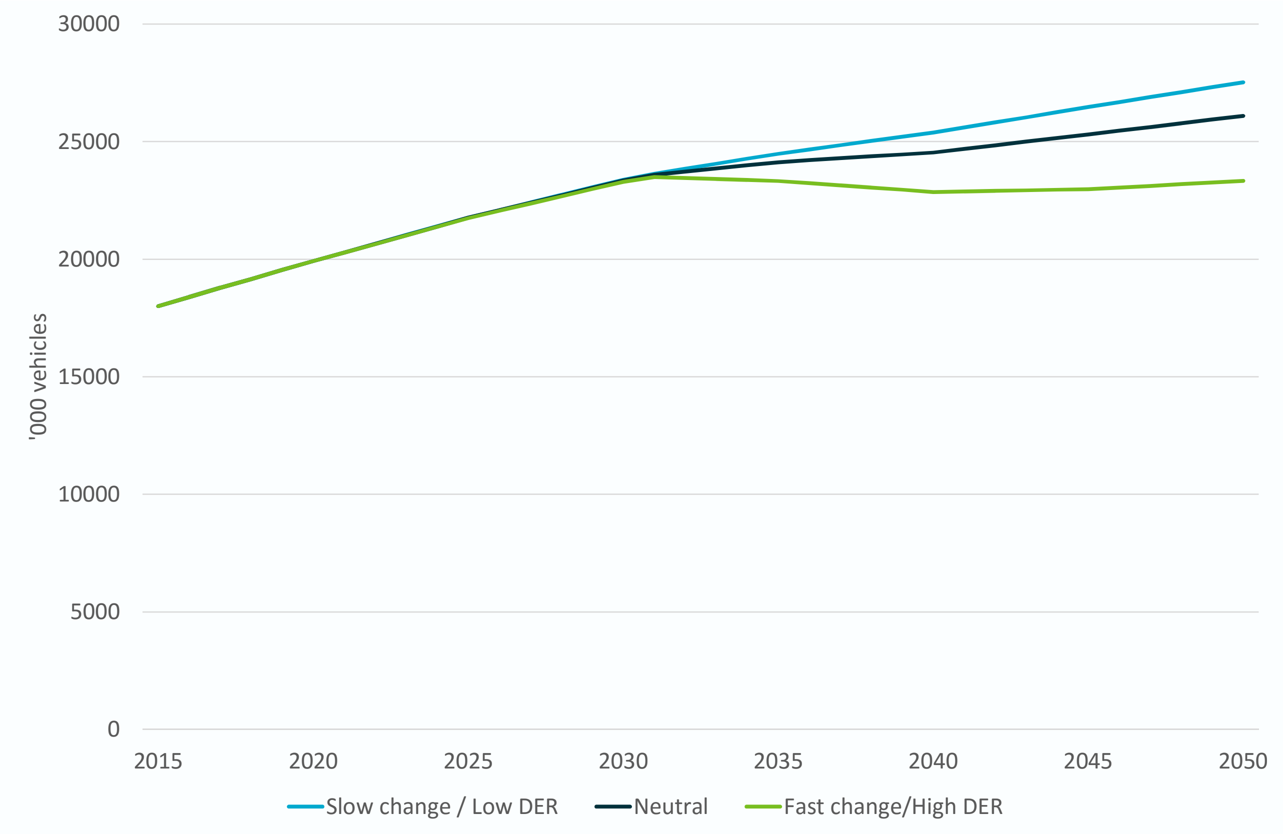


Figure 4-8: Projected national road vehicle fleet by scenario

4.10 Rooftop solar and battery storage market segmentation

For both residential and commercial customers the market that can most easily adopt rooftop solar are those with a separate owner-occupied building. Multi-occupant buildings or those that are not owner-occupied require more complex arrangements (business models) in order to extract and share the value of rooftop solar. This latter group is therefore a smaller market segment. Table 4-8 and Table 4-9 outline how large these market segments are assumed to be in each scenario and their implications for the overall size of the rooftop solar market. The assumptions are based on housing and ownership data discussed elsewhere in this report. The availability of commercial building data is not as good as residential, and consequently there is greater uncertainty in those assumptions.

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.

The battery storage market is assumed to be a subset of the rooftop solar market since the main motivation for storage is improving the utilisation and financial returns from rooftop solar. In reality there may be a small residential and commercial battery only market. For example, commercial customers may use storage to minimise capacity costs, particularly in the South West Interconnected System where capacity market costs are shared out according to customer contribution to demand peaks.

We impose the rooftop solar maximum market shares on the batteries' adoption curves. However, since the payback period for solar with integrated batteries does not reach the same level as for solar alone, in practice, batteries only reach a fraction (typically a third) of the total addressable market (all solar owners) in the projections.

Table 4-8: Non-financial limiting factor and maximum market share for residential rooftop solar

		Neutral	Slow change	Fast change	High DER	Low DER	Rationale/formula
Limiting factors							
Separate dwelling share of households	A	58%	57%	62%	63%	55%	Based on housing industry forecasts
Share of home owners	B	59%	58%	62%	63%	57%	Based on historical trends
Multi-occupant buildings able to set up internal retailing of solar	C	5%	2%	13%	15%	0%	Scenario assumption
Single occupant building owners able to sell directly to occupant or another peer (virtually)	D	3%	1%	6%	8%	0%	Scenario assumption. Landlords of single occupant buildings have more barriers to retailing
Rooftop solar maximum market share		42%	35%	57%	62%	32%	Formula=(A*B)+C+D

Table 4-9: Non-financial limiting factor and maximum market share for commercial rooftop solar

		Neutral	Slow change	Fast change	High DER	Low DER	Rationale/formula
Limiting factors							
Separate dwelling share of businesses	A	40%	38%	42%	43%	37%	Data limited. Scenario assumption
Share of business building owners	B	24%	23%	27%	28%	22%	Data limited. Scenario assumption
Multi-occupant buildings able to set up internal retailing of solar	C	5%	2%	13%	15%	0%	Scenario assumption
Single occupant building owners able to sell directly to occupant or another peer (virtually)	D	3%	1%	6%	8%	0%	Scenario assumption. Landlords of single occupant buildings have more barriers to retailing
Rooftop solar maximum market share		17%	11%	30%	35%	8%	Formula=(A*B)+C+D

5 Results

The section presents the projections results. Except where state and territory results are shown the results are summed to the national level which includes the National Electricity Market (NEM), South West Interconnected System (SWIS) and Darwin-Katherine Interconnected System (DKIS).

5.1 Rooftop solar adoption projections

All solar projections shown are in terms of effective capacity with an assumed degradation rate of 0.5% per annum for each year of life and across the whole stock. Warranties imply closer to 1% but include a margin to be conservative. In reality the degradation rate will not be constant but vary over the life of the panels and by type of panel.

5.1.1 Residential

Compared to projections undertaken in 2018, actual residential rooftop solar capacity is lower in FYE2018 and this early adjustment makes the Neutral scenario lower over the projection period (Figure 5-1).

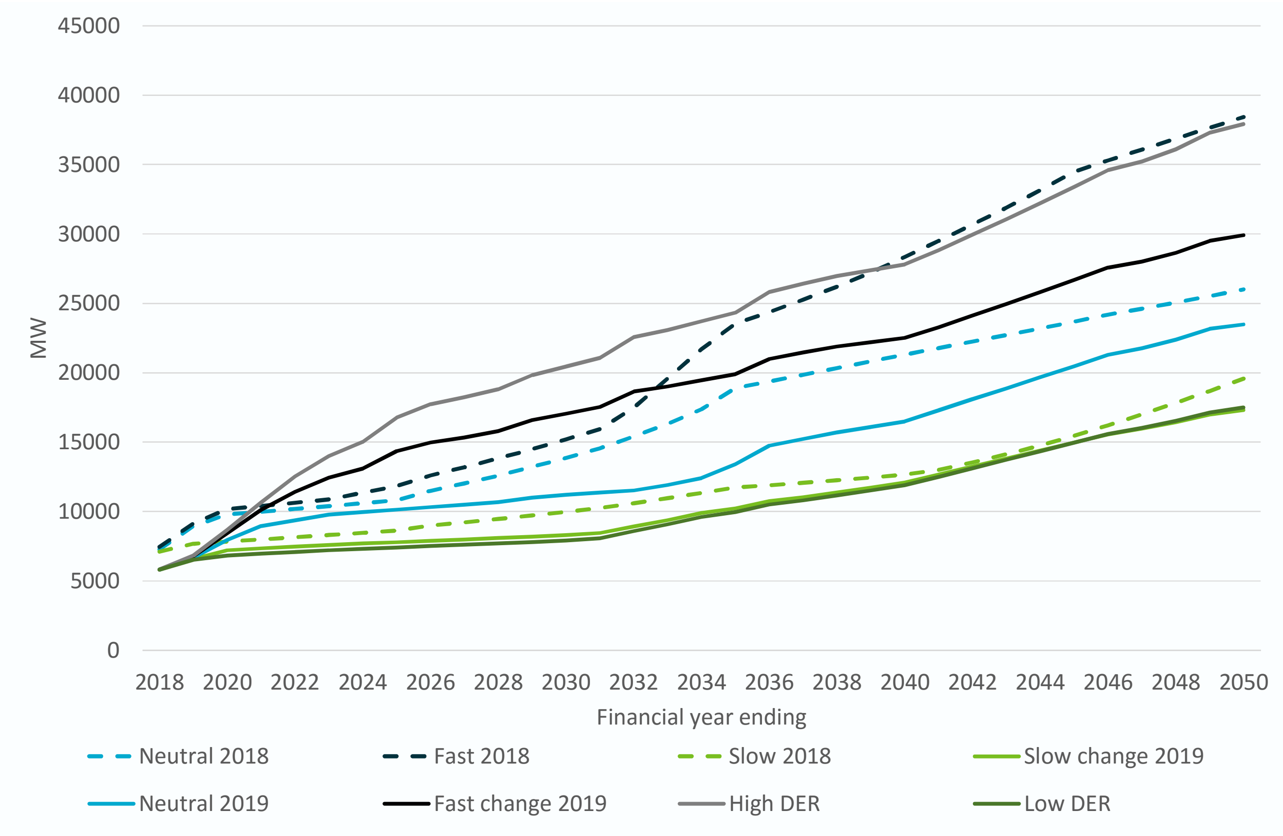


Figure 5-1: Residential rooftop solar capacity by scenario

After the FYE2018 adjustment, the trend for all the scenarios is otherwise in line or lower than the previous years' projections, reflecting that the key drivers remain similar or slightly worse. Rooftop solar subsidies are mostly unchanged[18]. In the next five years there is a stronger expectation that retail electricity prices will ease in most states. In the post-2030 period, retail electricity price assumptions are flatter than previous assumptions. However there are still some modest increases in retail electricity prices in some states leading to a slight acceleration in growth in 2030 in Slow Change and Low DER and in the early 2030s in the Neutral Scenario. There have also been some adjustments to the assumed market saturation levels which are developed based on expected availability of separate dwellings, home ownership levels and business model innovation.

5.1.2 Small scale commercial

Commercial rooftop solar systems below 100kW are eligible for the same small-scale renewable scheme subsidies as residential systems. Commercial electricity load is also more aligned with solar output. As such one might expect commercial solar adoption to be even higher than residential. However, there are fewer commercial premises and the shorter lives of business means those buildings are more likely to be rented. Consequently, commercial rooftop solar is around one sixth the capacity of residential solar. The 2018 projection for FYE2018 is very slightly lower (Figure 5-2). The expectation for the rate of increase in capacity for the next five years has been reduced reflecting broad expectations that retail electricity prices will ease during this period. A modest increase in retail electricity prices in the 2030s leads to some acceleration in capacity deployment from that time.

The remainder of differences in the scenario projections compared to 2018 relate to assumptions around the maximum market share.

[18] New South Wales policies announced during the March 2019 election have not been included due to a lack of detail available. Victorian policies announced to be implemented beyond the next election in the second half of 2019 have also not been included. These could lead to higher adoption in those states.

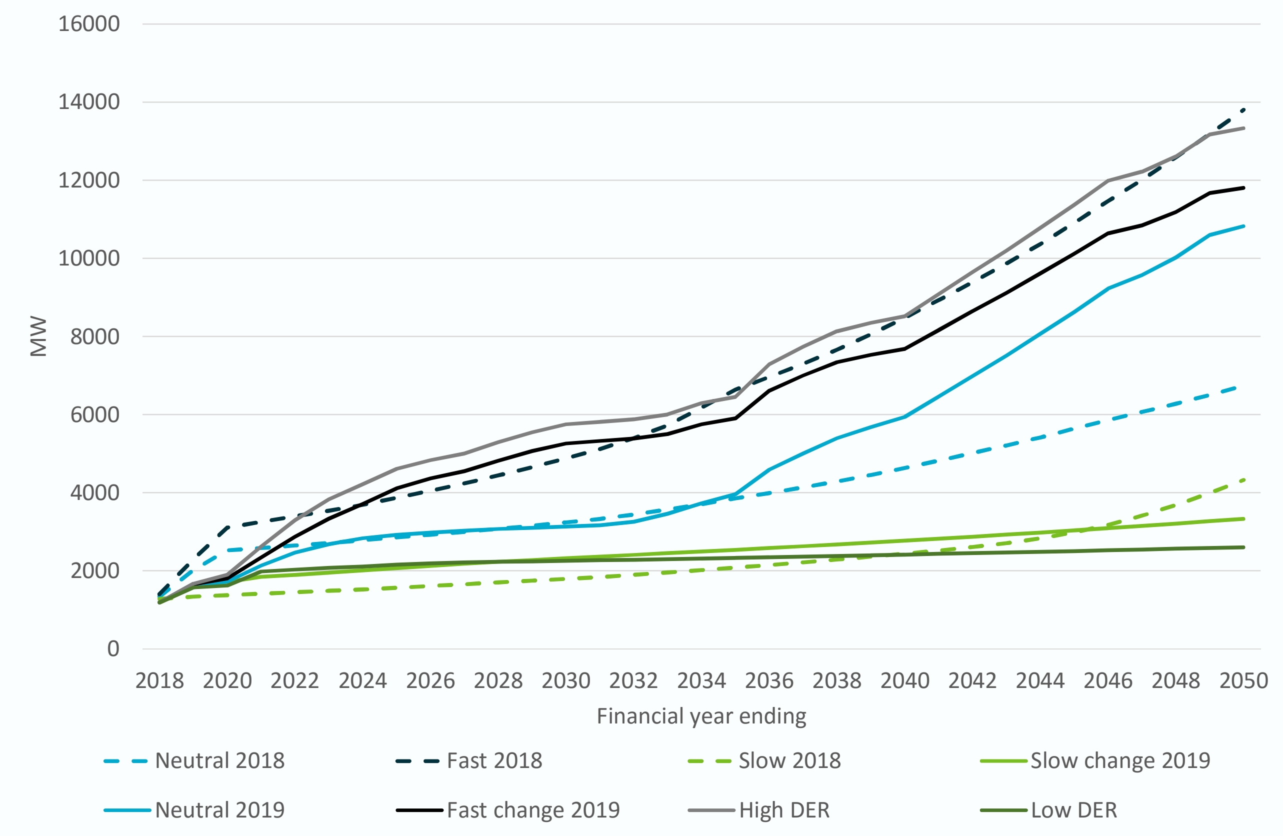


Figure 5-2: Small-scale commercial rooftop solar capacity by scenario

5.1.3 Commercial non-scheduled generation

Commercial non-scheduled generation is eligible for large scale renewable electricity generation certificates (LGCs) and the price of LGCs has fallen to around $34/MWh in early 2019. The 2018 projections assumed that the LGC price would fall to zero during the 2020 to 2030 period of the Large Scale Renewable Energy Target (LRET). However, those projections did not account for more than a 50% reduction occurring by 2019. As such the new projections are lower (Figure 5-3), particularly in the next five years when the LGC price assumptions are most different. Offsetting the poorer outlook for LGC prices is the prospect of Queensland and Victorian governments supporting direct payments to new solar generation projects to help meet their renewable energy targets. It is assumed that projects in those states are able to access additional subsidies that do not fall to zero. These subsidies are strongest in the Fast change and High DER scenarios. The Low DER scenario also has stronger growth due to the assumption of relatively reduced crowding out of the midday electricity price by customer owned rooftop solar.

The reduced LGC price results in flat to slow deployment of new non-scheduled generation capacity in the early 2020s. However, as solar photovoltaic costs continue to fall and increased subsidies are made available an increased rate of investment resumes in the early to mid-2020s depending on the scenario.

Given the renewable policies in Victoria and Queensland, they are a major source of new solar capacity (Figure 5-5). The Australian Capital Territory also has renewable policies and experience strong growth. However, owing to its smaller population this only has limited impact at a national level.

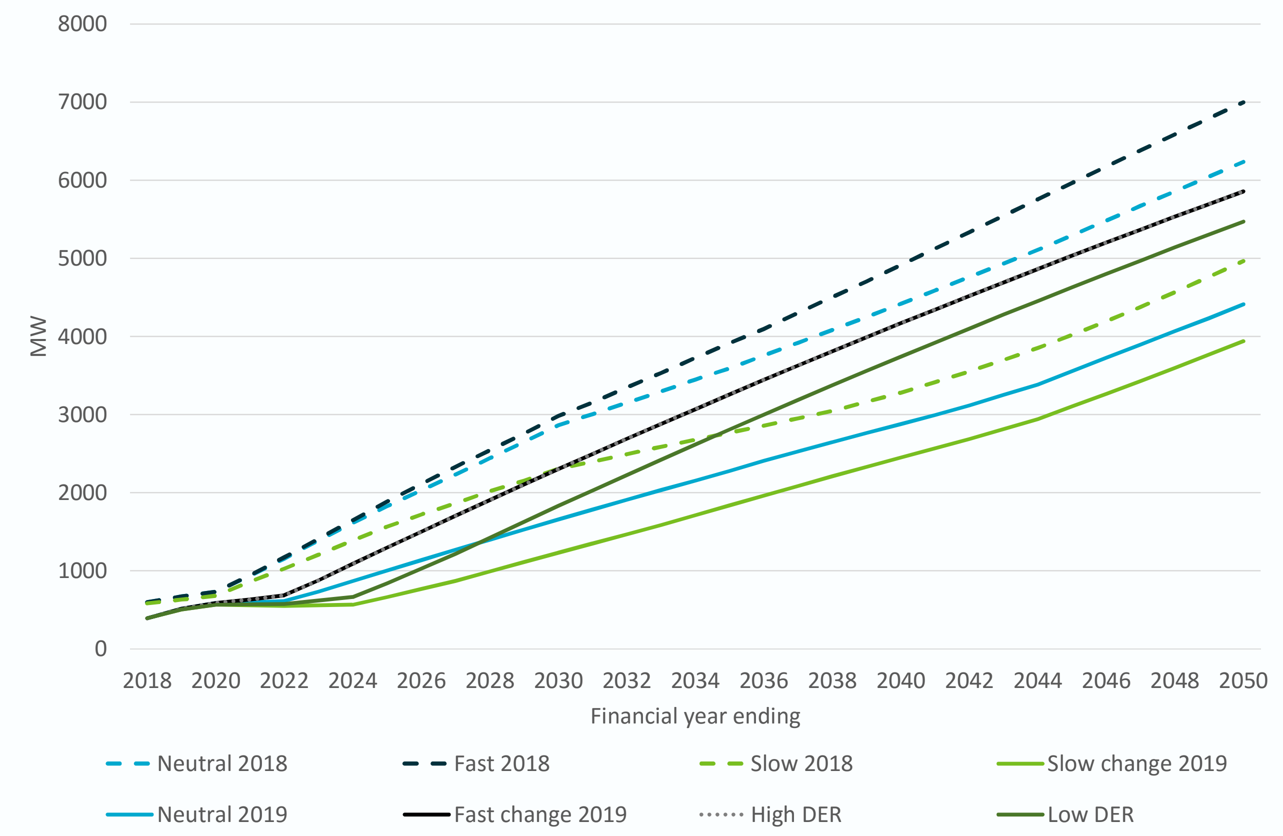


Figure 5-3: Capacity of large (>100kw) commercial solar by scenario

Systems in the 10MW to 30MW size are very lumpy in terms of their frequency of deployment. The projects may only occur every few years but are a large contributor to capacity when they do occur. At a national level, they remain the largest of the three size category grouping in 2018 and also the source of the greatest commercial growth to 2050 (Figure 5-4). However at state level the 10kW to 100kW category of solar photovoltaic capacity is sometimes the larger category (e.g. in the SWIS).

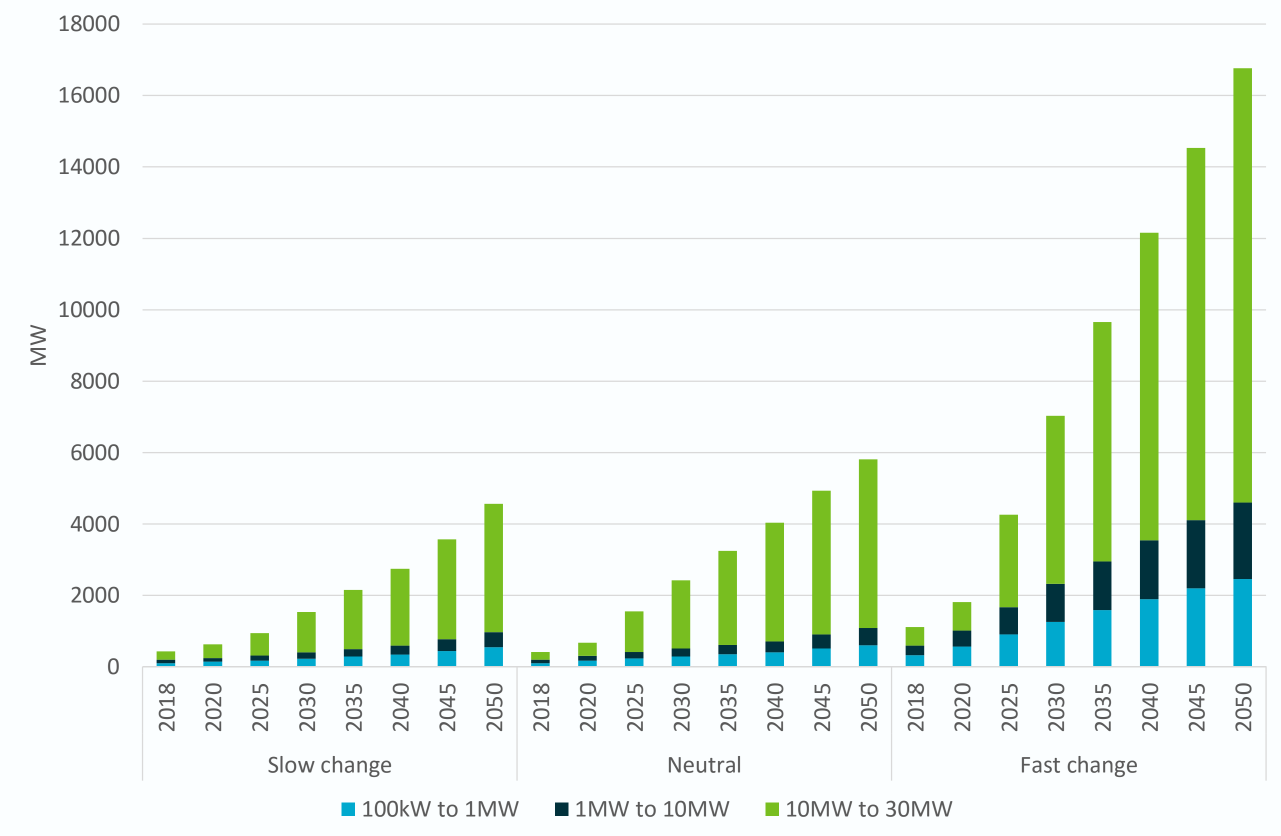


Figure 5-4: Breakdown of solar system sizes contribution to capacity additions under the Neutral scenario

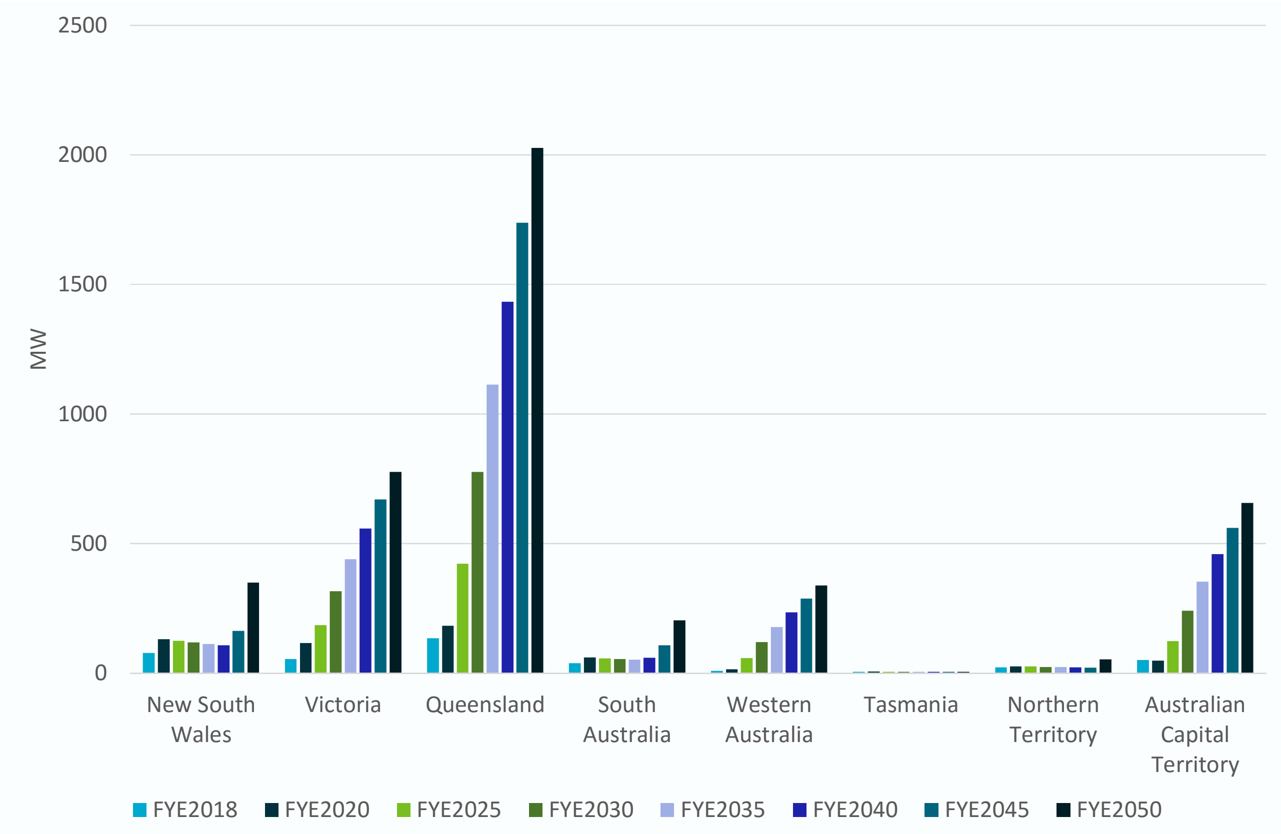


Figure 5-5: Large commercial solar capacity by state under the Neutral scenario

5.2 Battery adoption projections

5.2.1 Residential

Residential battery sales remain modest compared to rooftop solar at around 20,000 installations per year and only increased by around 20% in 2018 compared to the previous year (Sunwiz, 2019). With the industry starting from such a low base, this makes projecting the future adoption very uncertain. Every rooftop solar owner could potentially consider installing battery storage to improve the onsite utilisation of their solar generation and in doing so avoid more grid imports. However, the relatively higher payback period for adopting battery storage compared to rooftop solar remains as a barrier for most potential customers.

While we might define the current market as an early adopter group, as battery costs fall over the longer term, payback periods are expected to improve and subsequently increase the rate of adoption. While we are confident of technology costs reductions over the longer term, the revenue equation for battery storage is expected to remain uncertain for some time. The value of flexible load in Australia's electricity market and the range of market arrangements under which owners will be rewarded are not settled.

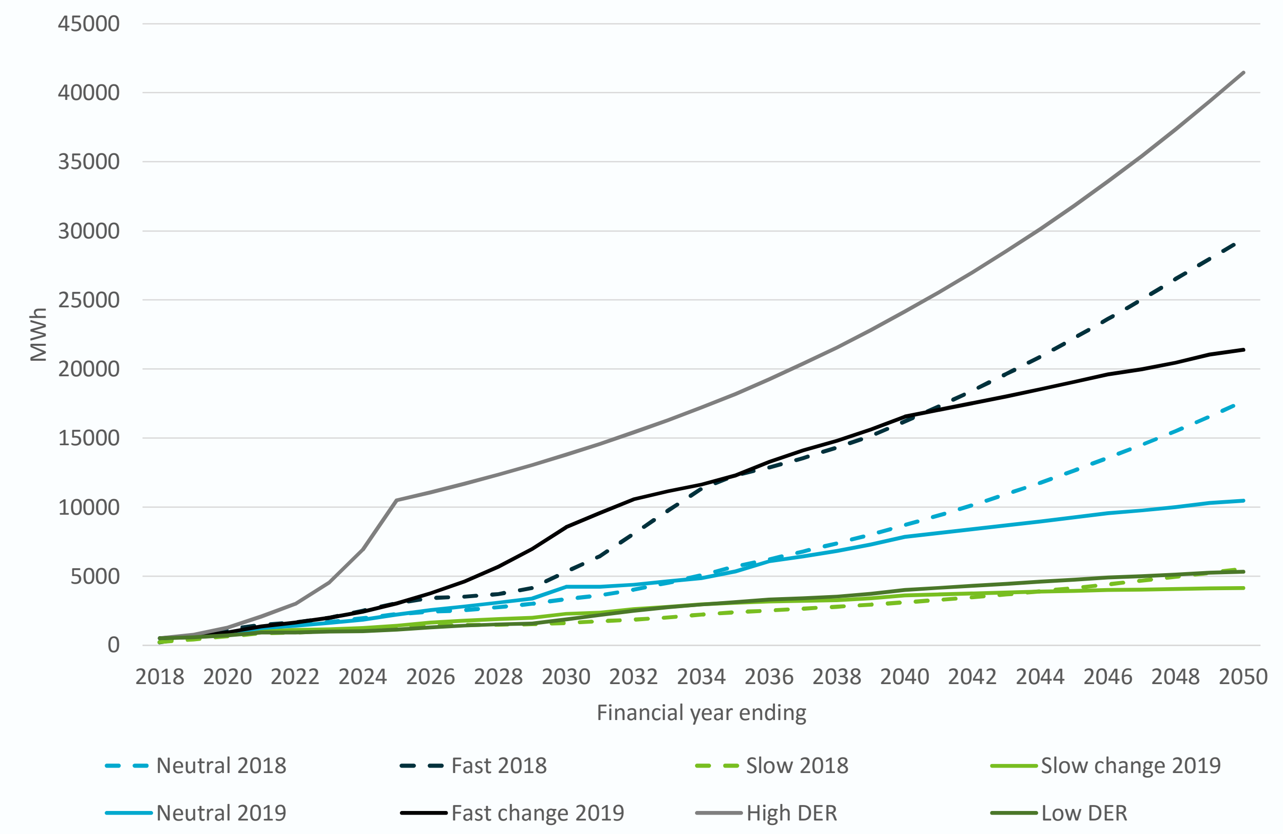


Figure 5-6: Capacity of residential battery storage by scenario

Given this level of uncertainty, we have widened the range of the projections compared to 2018. The Fast and High DER scenarios allow for the potential for attractive remuneration for owners if they make their batteries available for providing system services. In addition to the South Australian scheme supporting adoption of 40,000 batteries which was included in all scenarios, the High DER scenario assumes a broader subsidy scheme is available for batteries such that a $2000 subsidy is available in all states in the decade 2020 to 2030. The subsidy begins at $2000 and declining over time. We also cap the rate at which the subsidy can be accessed and consequently the growth peaks in 2025. The subsidy is designed to overcome the relatively high payback period that is causing slow adoption and as indicated in Figure 5-6 is successful in driving an accelerated rate of adoption during that period, slowing to a more moderate rate as the subsidy phases out.

The Slow, Low DER and Neutral scenarios assumed the majority of customers are using batteries mainly to shift solar with a smaller (but growing) minority accessing smarter tariffs or contributing to grid services resulting in more modest growth in installations.

5.2.2 Commercial

The current capacity of commercial battery storage is very low with most batteries installed at residential premises. Commercial customers tend to have a stronger daytime demand and are better able to use their solar output. As such there is a reduced need to add storage in order to achieve good utilisation of on-site solar. An exception is that where the demand charges of larger commercial customers are assigned according to their contribution at system peak times, it may be worth installing batteries to reduce customer peak demand contribution.

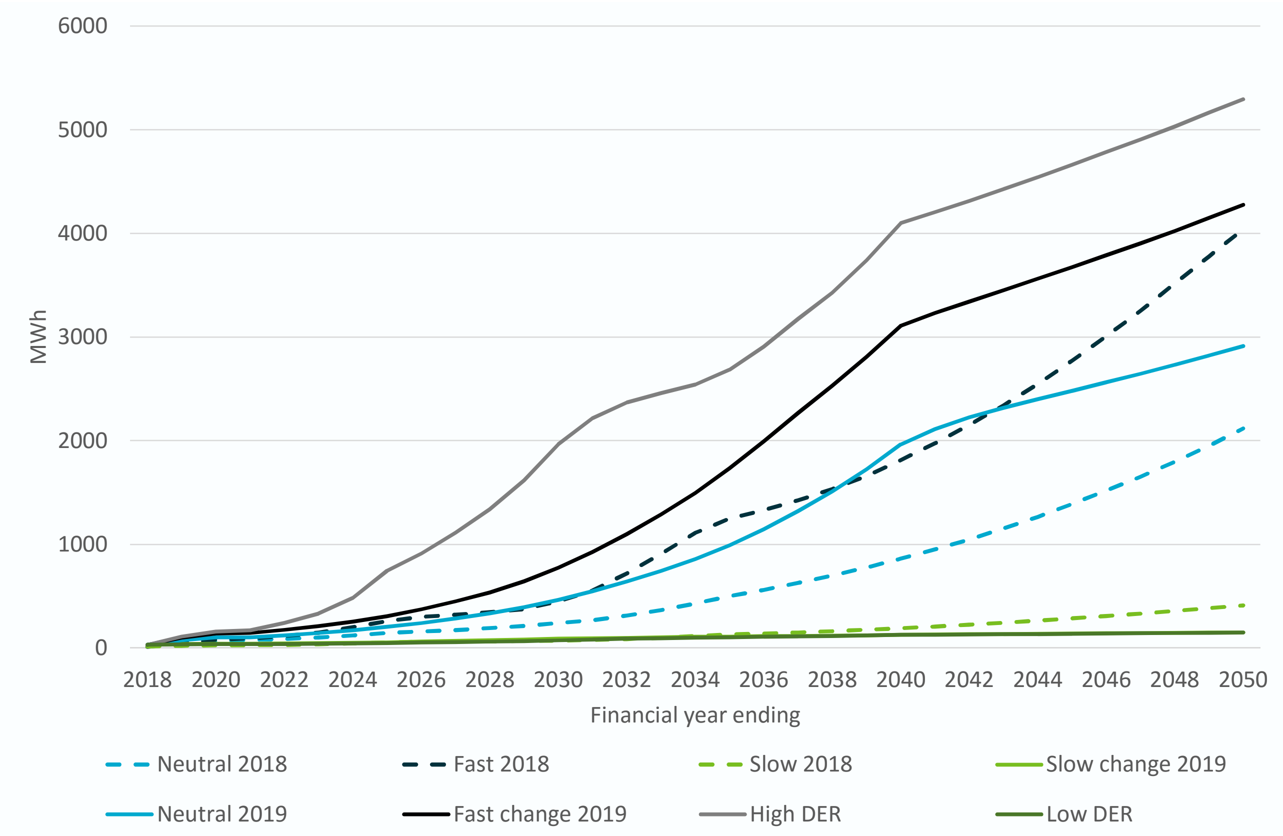


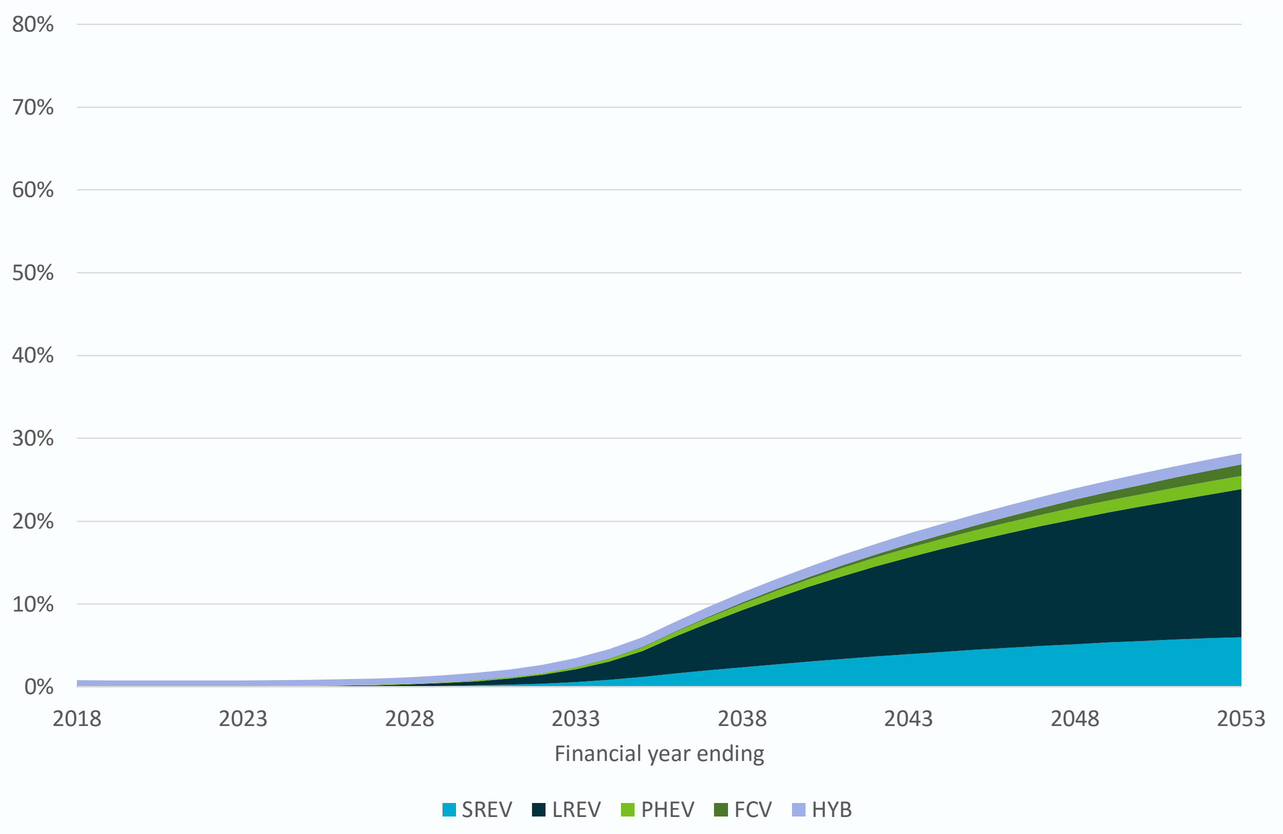
Figure 5-7: Commercial battery storage capacity by scenario

Given this different approach to the use and benefits of storage, the commercial battery adoption projections differ somewhat from the residential sector. The commercial sector takes longer to establish significant growth. However, like the residential sector the range of scenario outcomes is wider than was previously projected in 2018, recognising the uncertainty in the benefits to customers.

Under the High DER scenario the commercial sector is also eligible for the $2000 subsidy from 2020 and experiences a period of enhanced non-linear growth in the early 2020s which slows to a more linear rate as the subsidy phases out. By 2040 retail prices are stable and the last of the battery pack and balance of pant cost reductions have been delivered and growth slows to a steady rate.

5.3 Electric and fuel cell vehicle adoption projections

As electric and fuel cell vehicles reduce in cost consumers will have a variety of engine technology choices. We have modelled one short range vehicle which is electric and three long range options: long range electric vehicles with more batteries, plug-in hybrid electric vehicles with a small amount of battery range but a back-up internal combustion engine and fuel cell vehicles which are generally able to store enough hydrogen for long range driving. Hybrid electric vehicles have also been included, although they do not draw electricity from the grid given they are a relevant competitor.



SREV: Short range electric vehicle, LREV Long range electric vehicle, PHEV: Plug-in hybrid electric vehicle, FCV: fuel cell vehicle, HYB: Hybrid electric vehicle (does not charge from grid)

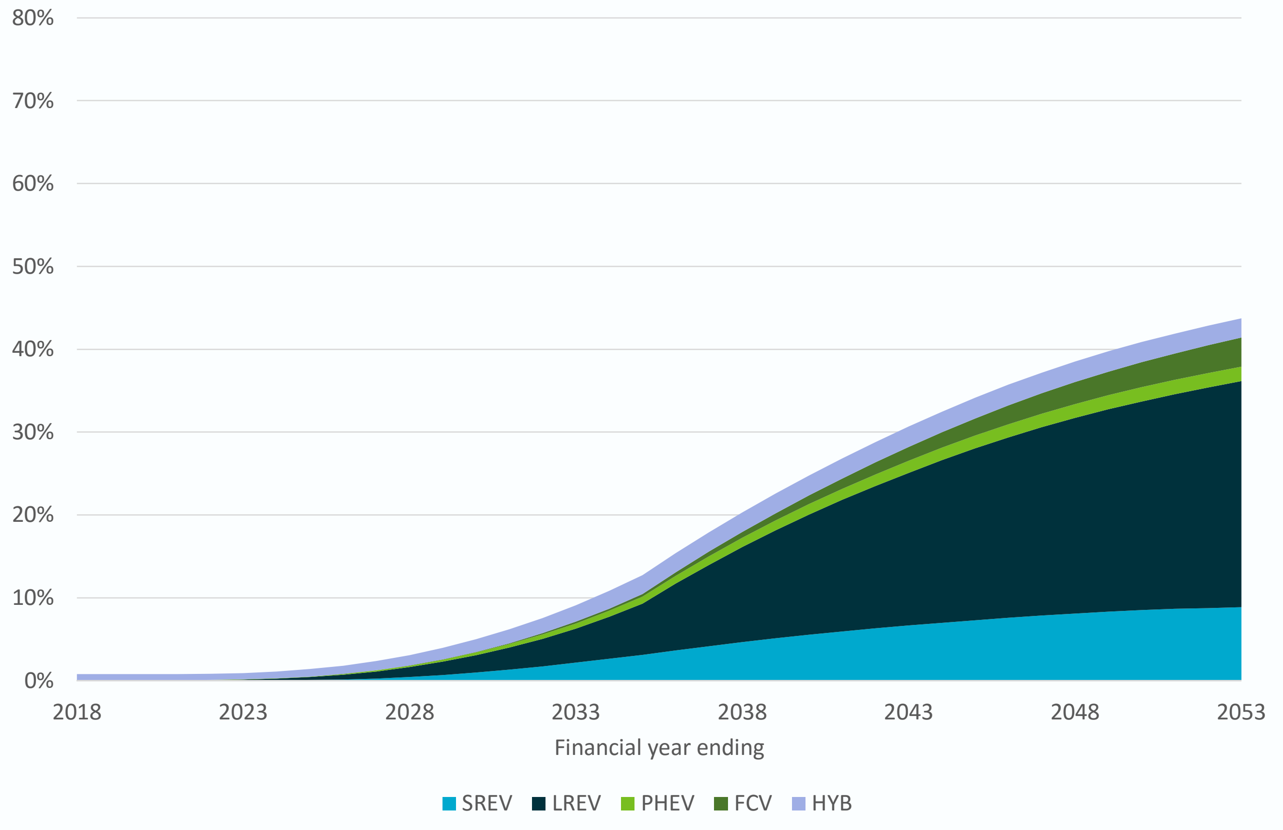
Figure 5-8: Share of non-internal combustion vehicles under the Slow change scenario

The longer range vehicles do not reach vehicle cost parity as quickly as the short range electric vehicles and this delays their adoption. On the other hand we assume that the market for short range vehicles is smaller (or saturates at a lower level)[19]. Each of the scenarios also has different

[19] See the formula for short range electric vehicle adoption in Table 4-6

assumptions about other market limiting constraints such as access to off-street parking for electric vehicle charging purposes or roll out of public charging or refuelling infrastructure.

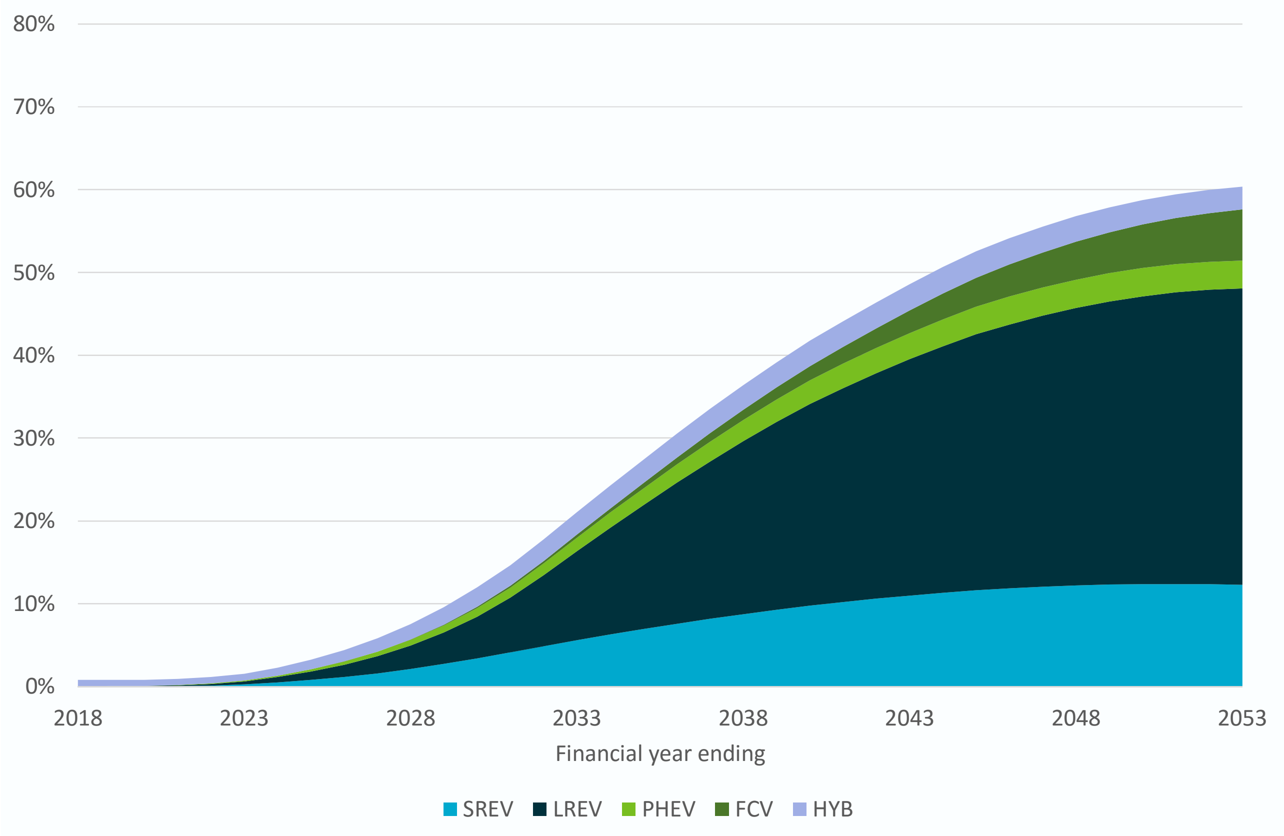
The differences in assumptions about infrastructure and the development of new business models to overcome them are the reason for the different levels of adoption that can be observed in Figure 5-8 to Figure 5-12. Under the Slow Change and Low DER scenarios the fleet share projecting forward 35 years is slightly above and slightly below 25% respectively with fleet share hardly growing until the early 2030s. Short and long range electric vehicles are the most popular of these alternative vehicles types reflecting their assumed lower ownership costs. The longer range electric vehicle market is the largest as it is the least constrained by infrastructure. Plug-in hybrid and fuel cell vehicles are mostly constrained by their relatively higher ownership costs.



SREV: Short range electric vehicle, LREV Long range electric vehicle, PHEV: Plug-in hybrid electric vehicle, FCV: fuel cell vehicle, HYB: Hybrid electric vehicle (does not charge from grid)

Figure 5-9: Share of non-internal combustion vehicles under the Neutral scenario

Under the Neutral scenario the fleet share of electric vehicles is growing faster from the late 2020s reflecting the assumption that vehicle costs reach their internal combustion vehicle upfront cost parity point in 2030. The rapid growth from this period results in a 35 year projection of 35% electric vehicle fleet share. The saturation of the market at that level reflects the assumptions that infrastructure constraints such as a lack of off-street home charging or lack of convenient public charging have not been completely resolved. This scenario also experiences modest fuel cell vehicle adoption from the late 2030s achieving around 4% fleet share in 35 years.

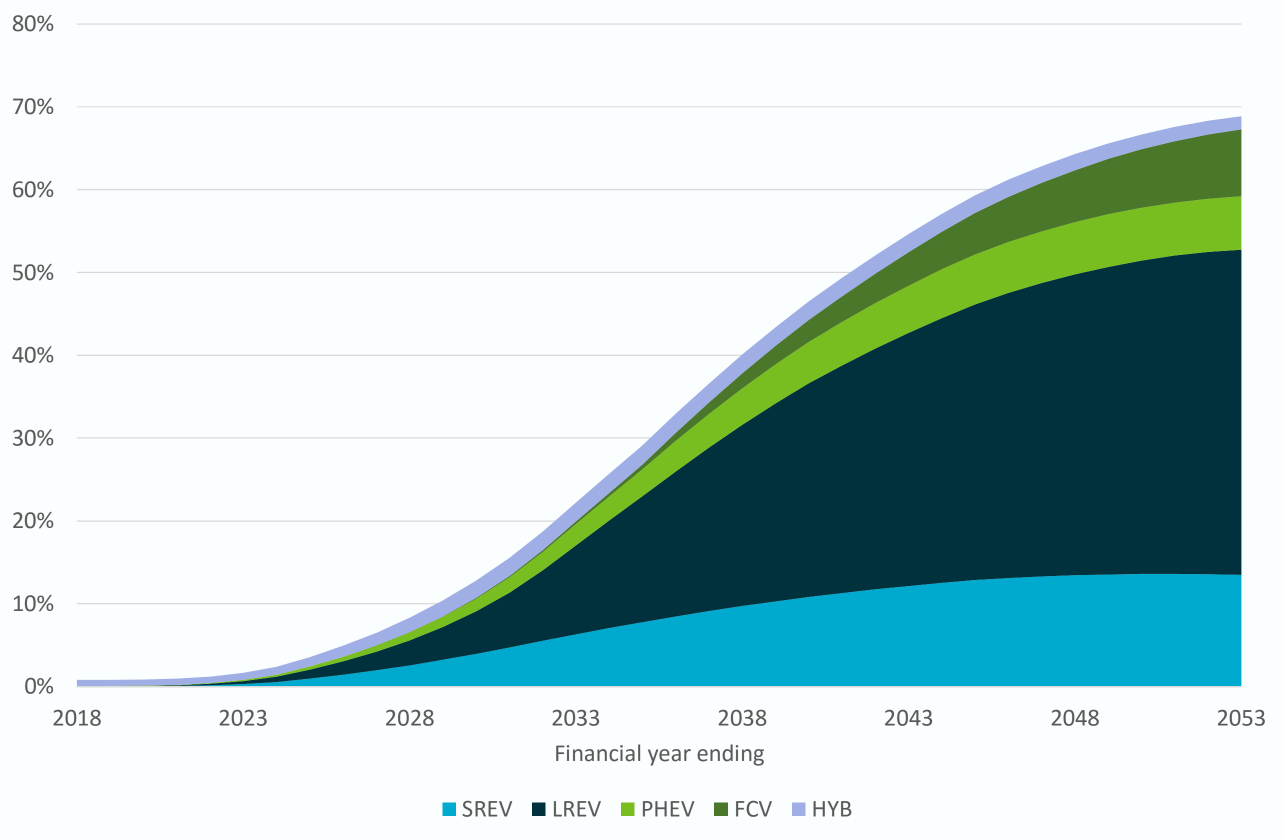


SREV: Short range electric vehicle, LREV Long range electric vehicle, PHEV: Plug-in hybrid electric vehicle, FCV: fuel cell vehicle, HYB: Hybrid electric vehicle (does not charge from grid)

Figure 5-10: Share of non-internal combustion vehicles under the Fast change scenario

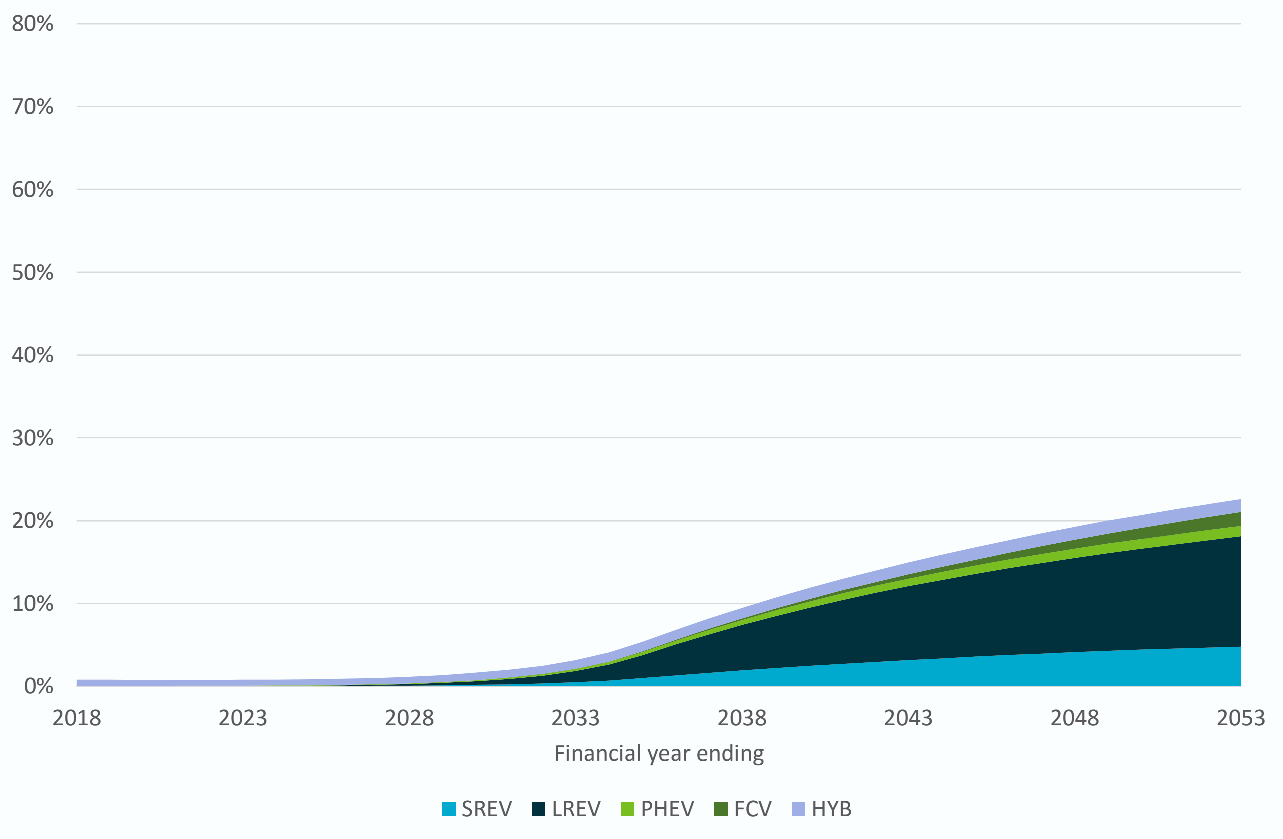
Both the Fast change and High DER scenarios assume that electric vehicles reach parity with the upfront cost of internal combustion vehicles in 2025, five years earlier than the Neutral scenario. They also allow for much larger potential market shares with the assumption that issues such as lack of off-street home charging and public charging infrastructure are alleviated to a greater extent. As a result of these assumptions the share of electric vehicles in the fleet is 9% and 11% by 2030 for Fast Change and Higher DER respectively. The 35 year projection for fleet share is 51% and 59% respectively.

Adoption of fuel cell vehicles is delayed in both scenarios but achieves a reasonable market share of 6% under the Fast change scenario and 8% under the High DER scenario over a period of 35 years.



SREV: Short range electric vehicle, LREV Long range electric vehicle, PHEV: Plug-in hybrid electric vehicle, FCV: fuel cell vehicle, HYB: Hybrid electric vehicle (does not charge from grid)

Figure 5-11: Share of non-internal combustion vehicles under the High DER scenario



SREV: Short range electric vehicle, LREV Long range electric vehicle, PHEV: Plug-in hybrid electric vehicle, FCV: fuel cell vehicle, HYB: Hybrid electric vehicle (does not charge from grid)

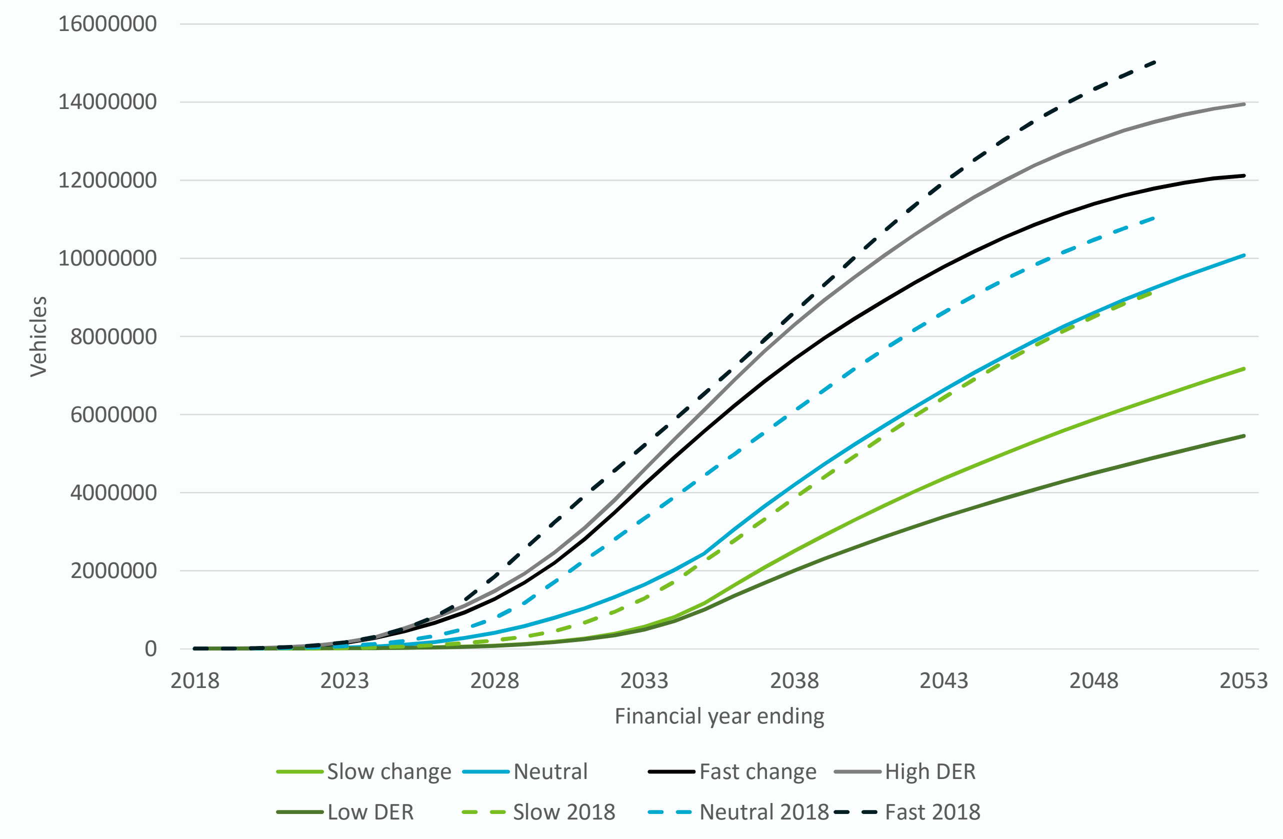
Figure 5-12: Share of non-internal combustion vehicles under the Low DER scenario

5.3.1 Comparison to previous projections

Compared to projections published in 2018 the number of electric vehicles is lower (Figure 5-13). This mainly reflects a lower projection for national vehicle sales. CSIRO changed its road activity and vehicle forecasting method to include a greater depth of analysis in relation to road transports' share of passenger and freight kilometre demand, changing costs of travel and the impact of autonomous and rideshare vehicles on the number of vehicles required to meet demand. The net outcome of these calculations is that growth in the vehicle fleet slows from the 2030s, particularly so in Fast change and High DER (Figure 4-8).

Secondary to the vehicle fleet size the market saturation levels for each scenario have been more methodically developed for this projection and this has led to some changes to that assumption. While the market size assumptions, which are developed across a number of tables in the previous section of this report, set an upper limit it may not be reached unless the payback period falls to enable the full potential to be met. Hence, when we assume delays in reaching cost parity with internal combustion vehicles this delays achievement of market potential.

A final factor to note is that the 2018 analysis did not consider fuel cell vehicles. Once this competing technology is taken into account it does have the effect of reducing the market for electric vehicles. Fuel cell vehicle uptake is projected to be modest but not insignificant. As such it does contribute to the relatively lower electric vehicle projections.



Electric vehicles includes the sum of short range, long range and plug-in hybrid electric vehicles

Figure 5-13: Number of electric vehicles by scenario

The sales share achieved by applying the assumed market potential adoption curves and financial assumptions underlying the payback period calculations are shown in Figure 5-14. It is clear that the Fast change and High DER scenarios increase their sales the earliest, from the start of the 2020s. This would coincide with the expected arrival of several new models of electric vehicles. The timing and rate of increase in sales share is delayed and lower in the Neutral scenario and further still in Slow Change and Low DER. Across the scenarios the rate of sales saturates at between 15% and 60% based on the examination of infrastructure constraints in the previous section. As discussed in that section, after electric vehicle reach parity adoption decisions are being driven mostly by infrastructure constraints (e.g. access to off-street parking and other factors in Table 4-6) which are not substantially changing over time. The sales share falls further from the late 2030s since we assume that most autonomous ride share vehicles are also electric vehicles and therefore they are more impacted than internal combustion engine vehicles by the reduced need for vehicle numbers under this mode of delivering passenger kilometres.

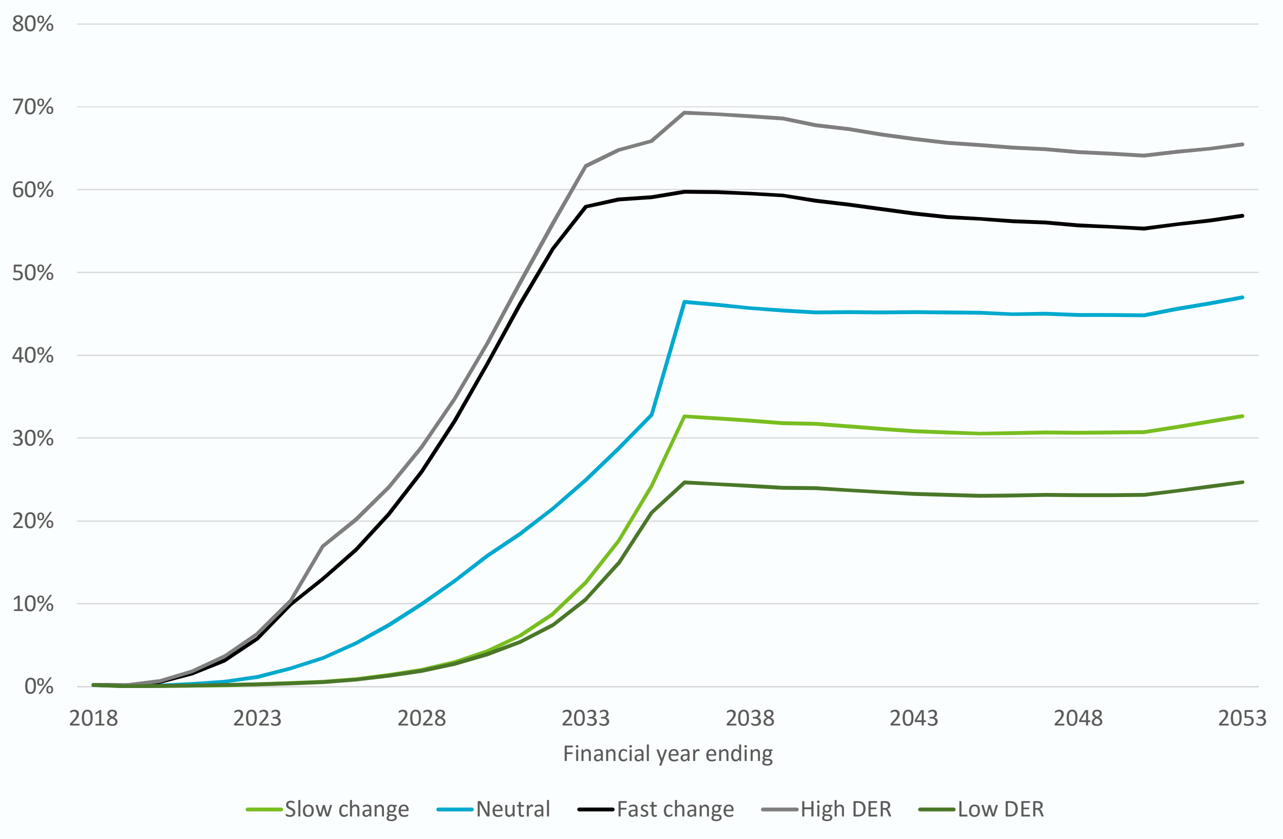


Figure 5-14: Electric vehicle sales share by scenario

The consumption of electricity from electric vehicles is directly related to the number of vehicles and their distance travelled. As such, the reduction in the projected consumption from electric vehicles simply reflects the reduced projected number of electric vehicles. Offsetting this reduction is additional demand for electricity from fuel cell vehicles. Assuming the source of hydrogen is the electricity grid, fuel cell vehicles are less efficient in their use of electricity and consequently each fuel cell vehicle uses around twice as much electricity as a battery electric vehicle. If we included the electricity consumption from fuel cells in Figure 5-15 it would add another 3,700 GWh to the Neutral scenario and 8,400 GWh to High DER by 2053.

Electric vehicle adoption is dominated by light vehicles – passenger and light commercial vehicles (Figure 5-16). However, some truck and bus adoption is expected over time and given the smaller size of the heavy vehicle fleet it does not require as many vehicles to reach a significant share. The vehicle type share is important not just for the volume of electricity consumed but for understanding what type of charging behaviour will be dominant which is discussed in the next section.

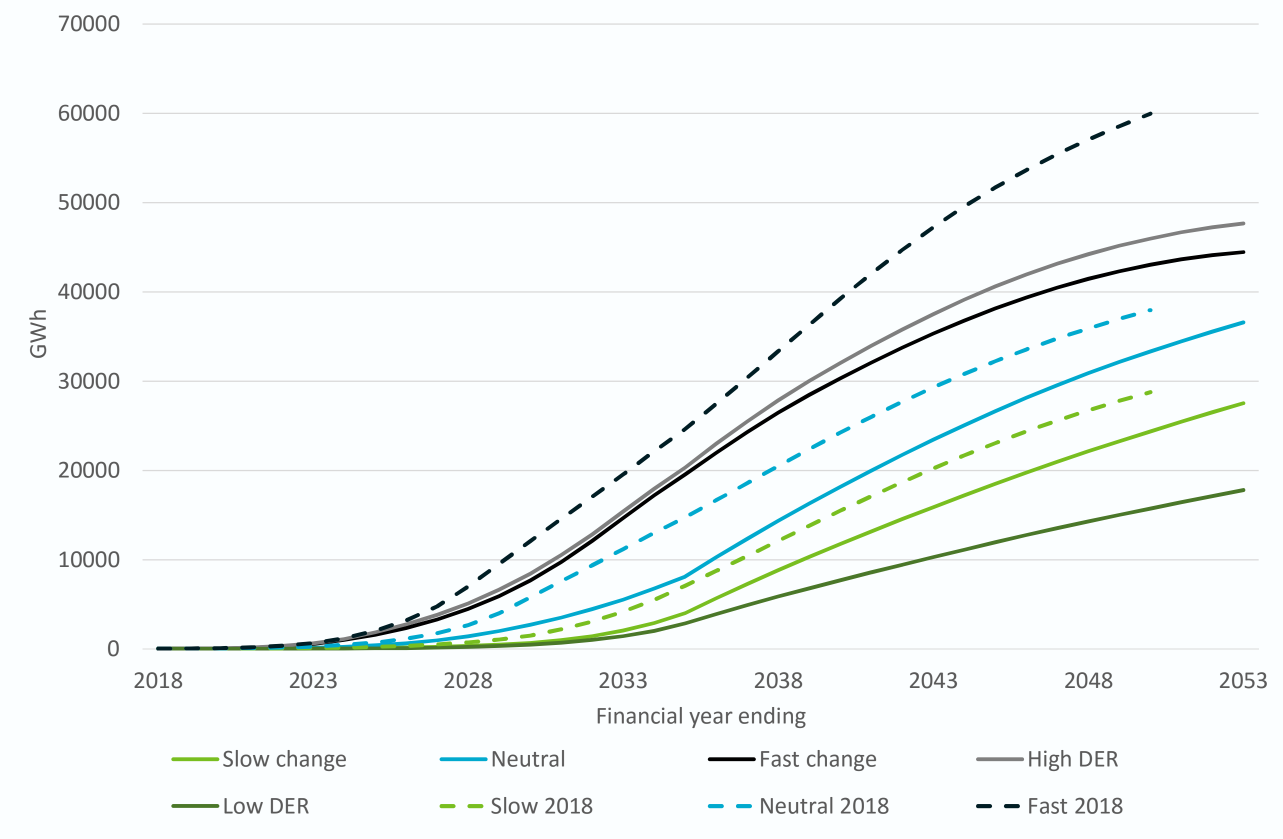


Figure 5-15: Electric vehicle electricity consumption by scenario

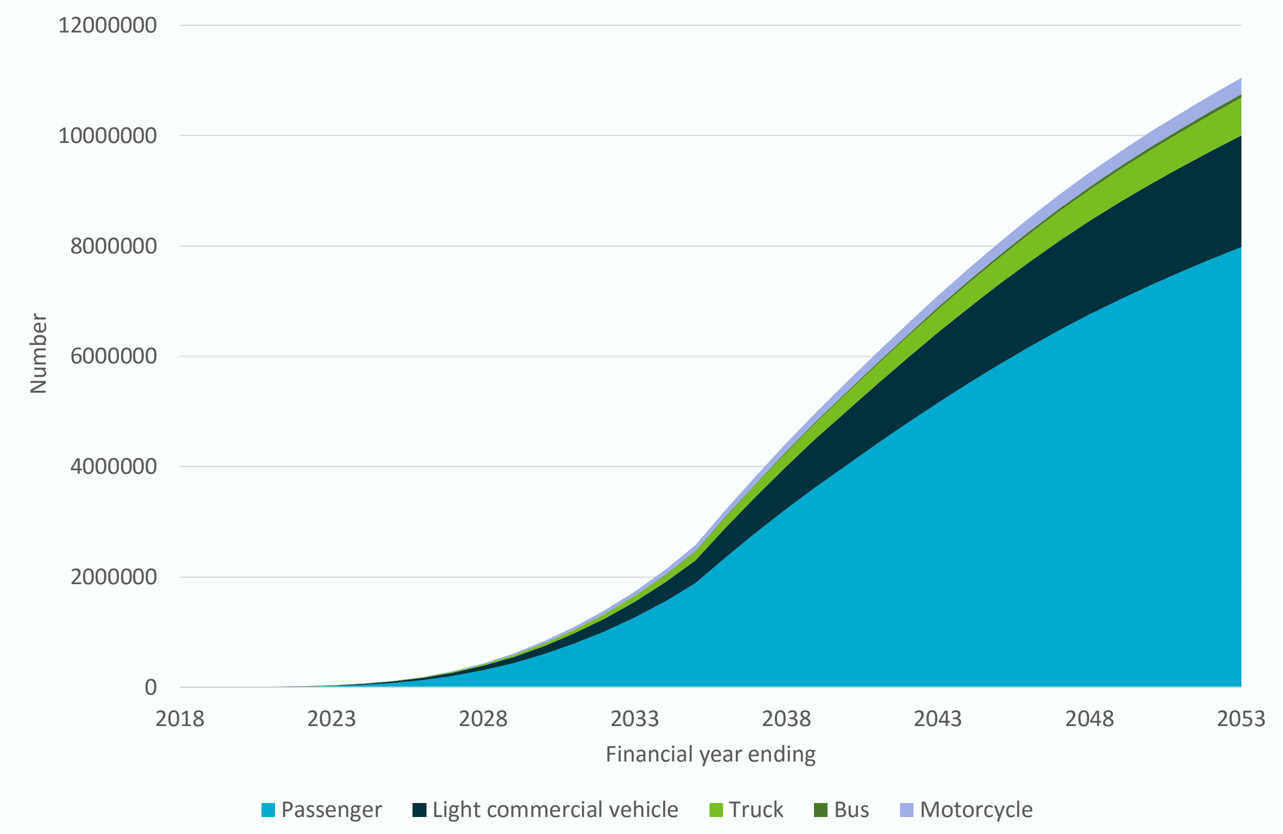


Figure 5-16: Electric vehicle numbers by vehicle type under the Neutral scenario

5.4 Electric vehicle load profiles

AEMO requires after-diversity electric vehicle load profiles to match against the vehicle projections in order to determine their impact on electricity demand. Australia lacks large participant electric vehicle load studies reflecting the small number of electric vehicles in Australia. Similar to the approach taken in 2018, we have used a UK study (Roberts, 2016) and modified it for Australia by adjusting each state for the average vehicle kilometres travelled and increasing the size of the peak to match the vehicle chargers available (rather than the size of the chargers used in the large participant study). We have also overlaid differences in travel on weekends versus weekdays and for different months of the year (Figure 5-17). This after-diversity convenience profile is then manually modified to create two additional profiles – day and night – to represent off-peak charging (Figure 5-18). The day time off peak profile is assumed to be more dominant later in the projection period when public vehicle charging is more prevalent and solar adoption has increased.

Figure 5-17: Factors for adjusting light and heavy vehicle charging profiles for month and weekend.

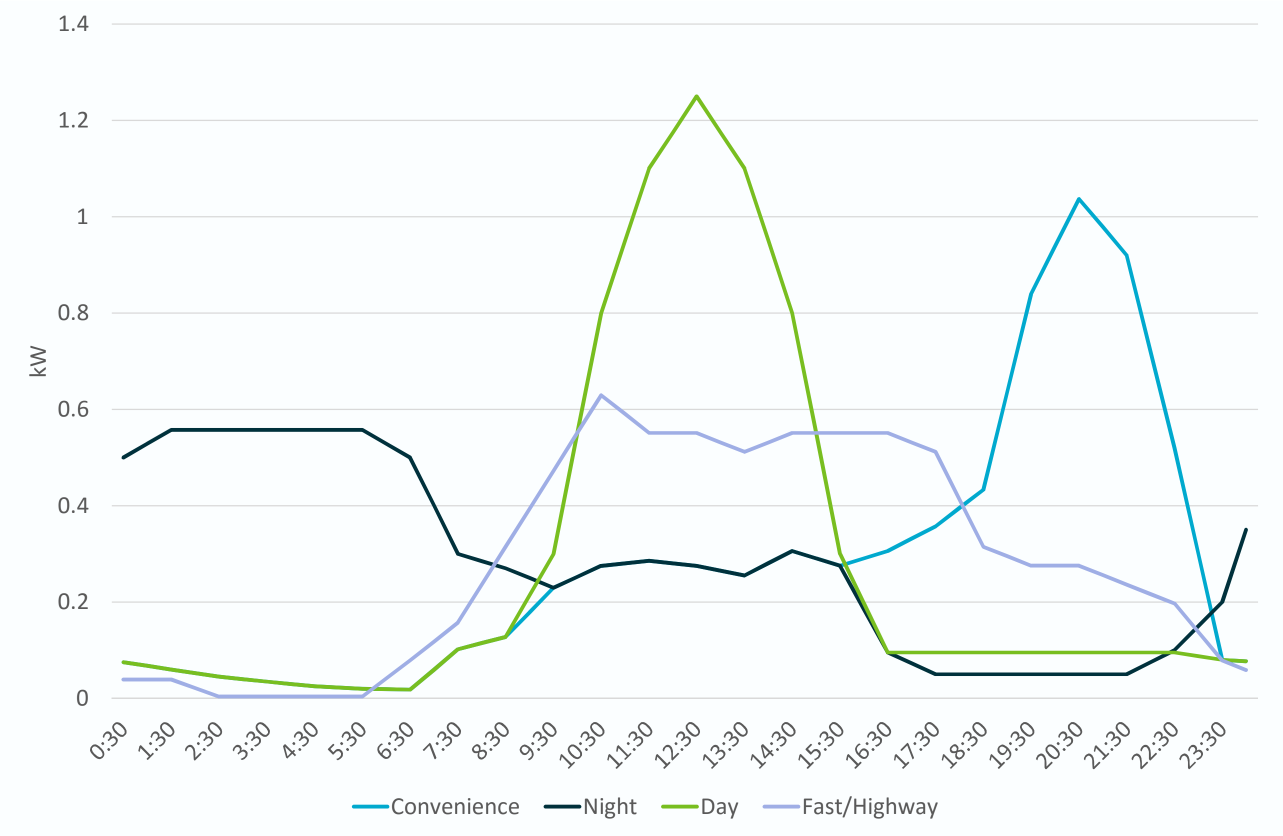


Figure 5-18: Passenger electric vehicle charging profiles (national annual average daily basis)

An additional profile for fast or highway charging has been added. This profile has been based on a mix of simulated and actual arrivals of vehicles at public fast charging in the literature (see for example, Chen et al 2016 and Wang et al 2016). This profile is fairly day oriented but also has a tail of demand which goes into the evening period. It tends to mimic the volume of traffic on roads but analysis also tries to take into account issues such as queuing and the number of chargers at a charging area. These different charging profiles are applied in the ratios that are set out for each scenario in the previous section.

The charging profiles for light commercial vehicles and buses are also shown in Figure 5-19 and Figure 5-20. These are based on available Australia studies (Mader and Bräunl 2013; Victorian Government 2013) and, as with the passenger vehicle profiles, modified to create additional profiles for day, night and fast charging. In each case the area under the chart is maintained to reflect state and territory average distance travelled for that vehicle type. The truck profiles are assumed to be the same shape as buses but with a different area under the chart to recognise the different energy requirements of trucks. Truck numbers are an amalgamation of smaller rigid and larger articulated trucks and so there is greater uncertainty about their energy consumption than other vehicle categories.

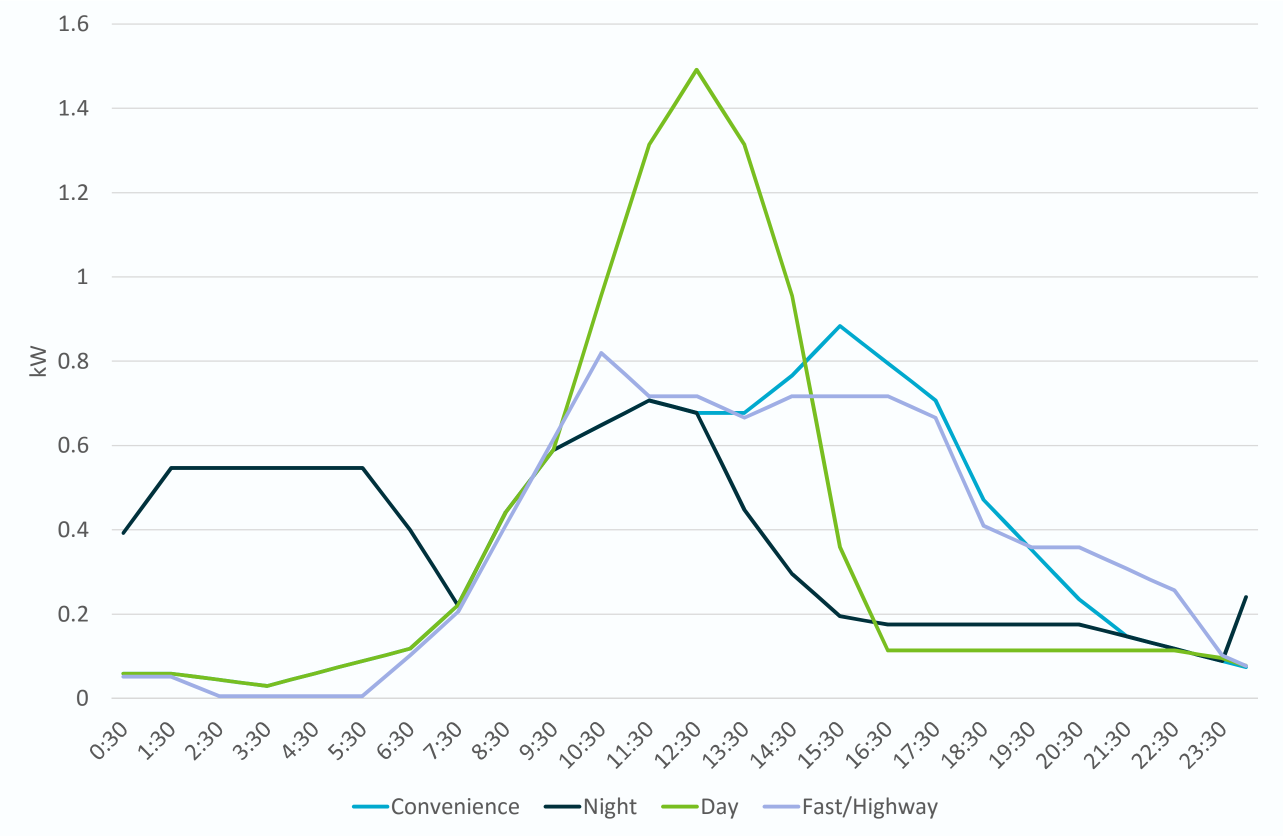


Figure 5-19: Light commercial electric vehicle charging profiles (national annual average daily basis)

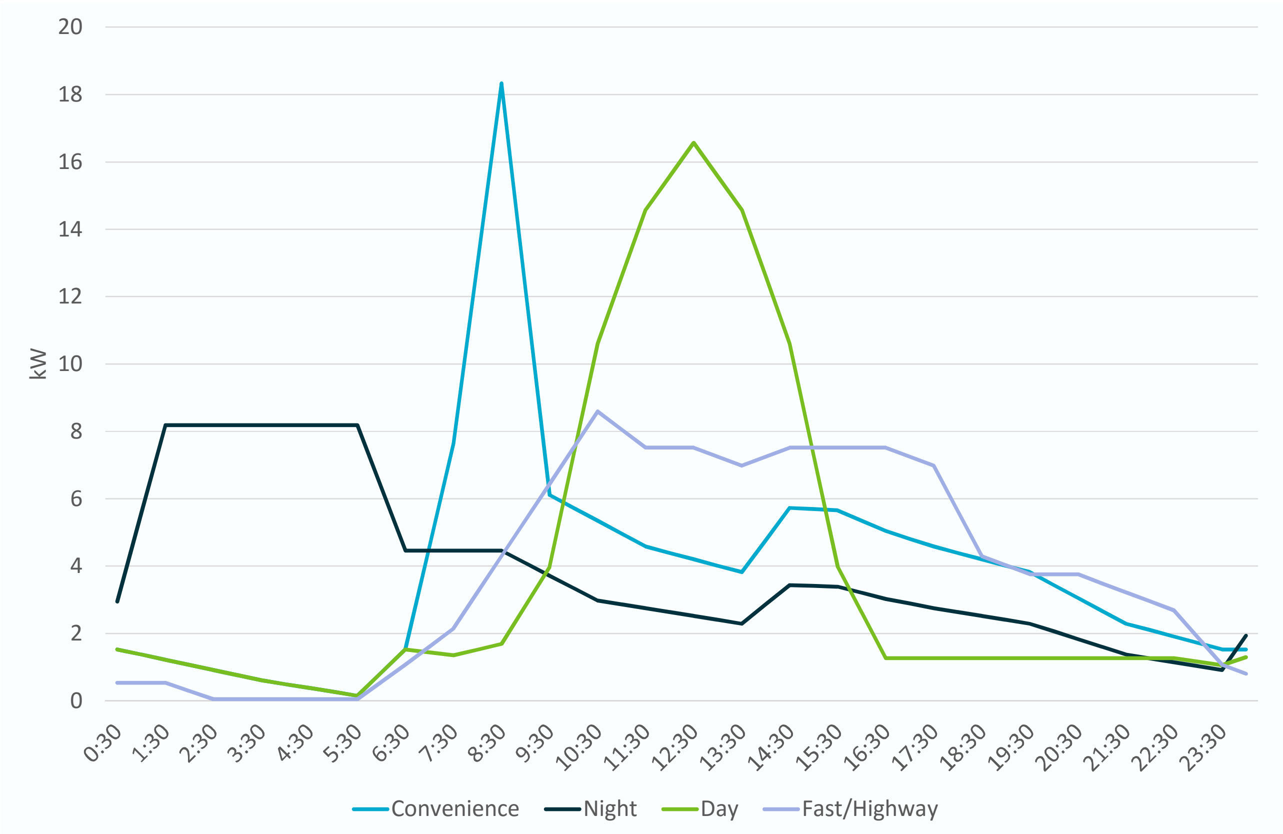


Figure 5-20: Bus electric vehicle charging profiles (national annual average daily basis)

5.5 Battery storage profiles

As discussed in the assumptions section, the two key battery profiles that have been designed for both residential and commercial customers are to shift solar (ShiftSolar) and to shift solar but with some extra steps to increase battery output during the peak period (ShiftPeak). These profiles are assumed to be used by customers not participating in any centrally coordinated schemes but rather as default set and forget operational procedures. The ShiftPeak profile might also be consistent with an aggregator optimising a battery on behalf of a customer who is signed to a time of use or demand tariff (see the discussion on the impact of these tariffs in Graham et al 2018). The ShiftSolar profile is consistent with optimal behaviour under a flat tariff.

As can be seen in Figure 5-21 and Figure 5-22 there are differences in outcomes from the two alternative operational procedures. The ShiftPeak profile assumes that customers charge up if their battery is not full at 4:00pm to ensure they can undertake a full discharge during the peak period if required. This only happens on low solar days and more so for customers for whom solar and storage is small relative to their load. The outcome is that this strategy increases the discharge during the evening peak, on average.

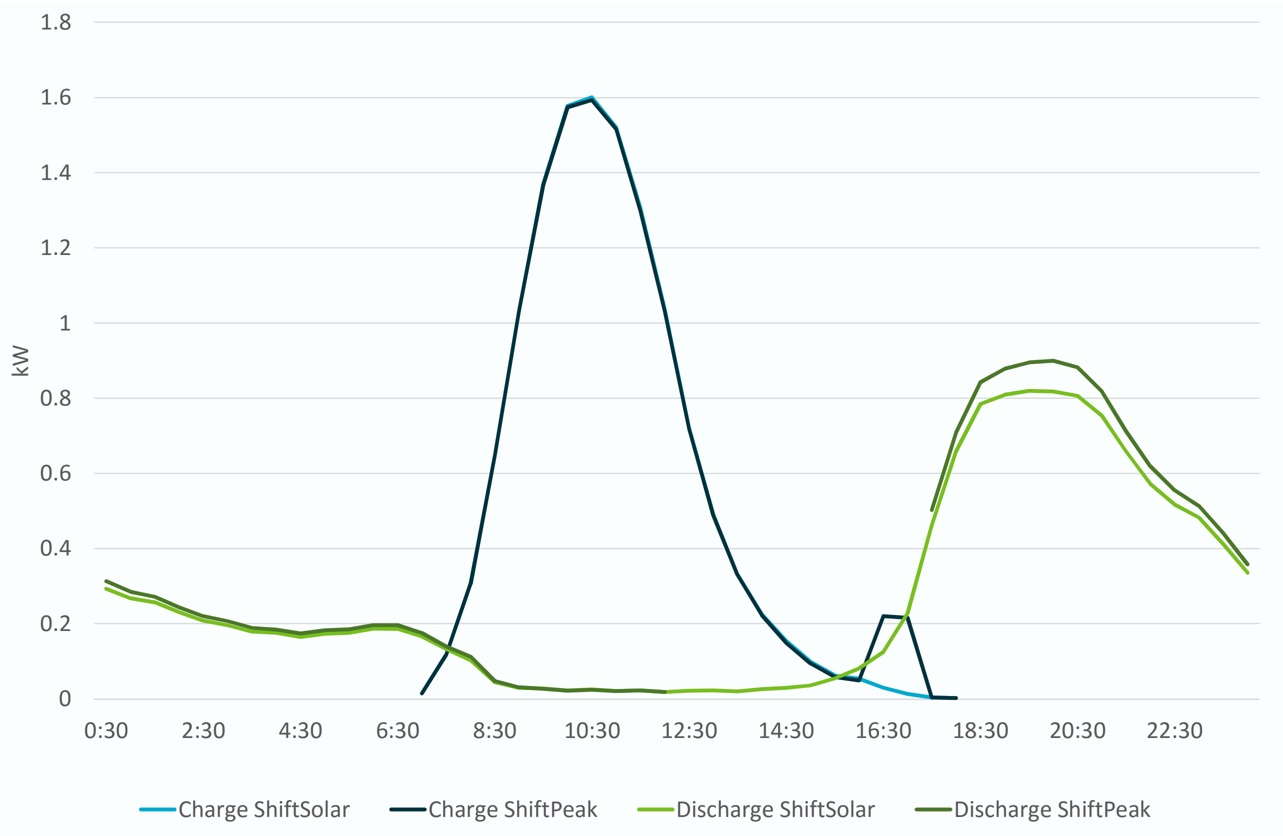


Figure 5-21: Average residential battery storage profiles (half hour ending, average of 90 days over summer period)

For commercial customers their solar generation is a closer match to their daily demand and so they have a bigger challenge in filling their battery. As a consequence, and in contrast to residential customers, they find under normal ShiftSolar charging their battery is fully discharged by around 8:00pm on average and more often before that time. Under the ShiftPeak strategy they delay discharging and charge up at 4:00 to 5:00pm and as a result are able to continue discharging at a significantly higher rate until around 8:30pm on average. This strategy may be sufficient to assist commercial customers in reducing their exposure to peak demand fees. Deeper analysis may discover alternative charging and discharging regimes combined with alternative sizing of battery and solar capacity that reduce peak demand further but would still need to be tested as to whether they produce a net benefit overall for the customer's electricity costs.

Figure 5-22: Average commercial battery storage profiles (half hour ending, average of 90 days over summer period)

5.6 Vehicle to home

Vehicle to home is a special case because customers adopting this approach discharge their vehicle battery through its typical driving cycles but also discharge the vehicle's battery to the home whenever it is located at home. As such the discharge profile for vehicle to home vehicles is simply the customer load when it is at home. The charging profile is designed to access the cheapest electricity possible (to make up for battery cycle efficiency losses) and as such is entirely concentrated on the 2 hours either side of midday to capture low cost solar generation (large scale or local). This profile only comes into play from the 2040s in the High DER scenario.

Appendix A Additional data assumptions

In this appendix we outline some key additional assumptions that were used to develop the adoption projections in addition to the scenario specific assumptions discussed in the body.

A.1 Technology performance data

Each technology can be described by a small number of performance characteristics with energy efficiency being a common one whilst others are specific to the technology. The following tables outline key performance data for rooftop solar, battery storage and electric vehicles.

A.1.1 Rooftop solar

Rooftop solar generation profiles were sourced from the AEMO. Table A.1 shows the average capacity factors from these production profiles.

Apx Table A.1 Rooftop solar average annual capacity factor by state, 2018-19

	Capacity factor
New South Wales	0.154
Victoria	0.142
Queensland	0.162
South Australia	0.154
Tasmania	0.136
Western Australia (SWIS)	0.139
Northern Territory	0.162

New residential solar panel sizes are set by the scenario assumption at 5kW (before degradation), however the existing average is 3.5 to 4kW. Given the much better match between commercial customer load profiles and solar output profiles, commercial solar system sizes are assumed to be matched to average daily peak.

Rooftop solar systems have been advertised with higher panel to inverter capacity ratios recently. This likely reflects the fact that subsidies are available on rooftop solar capacity. Licensing conditions for installers require that the inverter is no less than 75% capacity of the solar panels. Hence we might see an offer for 6.6kW solar with a 5kW inverter. Subsidies per watt of solar power capacity are declining (see discussion of STCs in the body of the report) and being replaced with rebates or low interest loans. Therefore, we would expect the current trend towards higher solar to inverter ratios to ease slightly. However, with the requirement for new inverters to provide reactive power which in that mode can only deliver 80% of the available real solar power, a larger inverter relative to the solar panel may become more the norm. Our assumption is that the ratio is currently increasing and will peak at 1.15:1 converging towards 1:1 on average in the long run.

The share of installed rooftop solar with a north orientation appears to be around 90%, with mostly West followed by east being the remainder[20]. We assume the ratio of north-facing falls to 70% by 2050 (with the other orientations proportionally gaining) owing to those buildings with less favourable orientations being in the late follower group. There is also expected to be a greater incentive for west orientation due to more customers responding to incentives to reduce demand during peak times.

A.1.2 Battery storage

For battery storage sizing we have chosen not to optimise size since the current market tends to only offer limited size ranges. We have looked at popular battery sizes and matched a larger battery to our large customer profiles and a battery around half that size to other customers (see Table A.2). Note that we do not need to explore larger kW power capacity batteries because, with a maximum power discharge and charge rate of the battery size in kWh divided by 2.6, the largest battery power capacity size we include can already absorb all power from a 5kW solar system. As such there would be little to gain from any larger battery power capacity size given rooftop solar size restrictions.

For commercial customers the battery system size in kWh is set proportional to the smaller of the two popular residential system battery to solar ratios. Commercial systems should need a lower storage to solar ratio because their solar is much better matched to the commercial load profile.

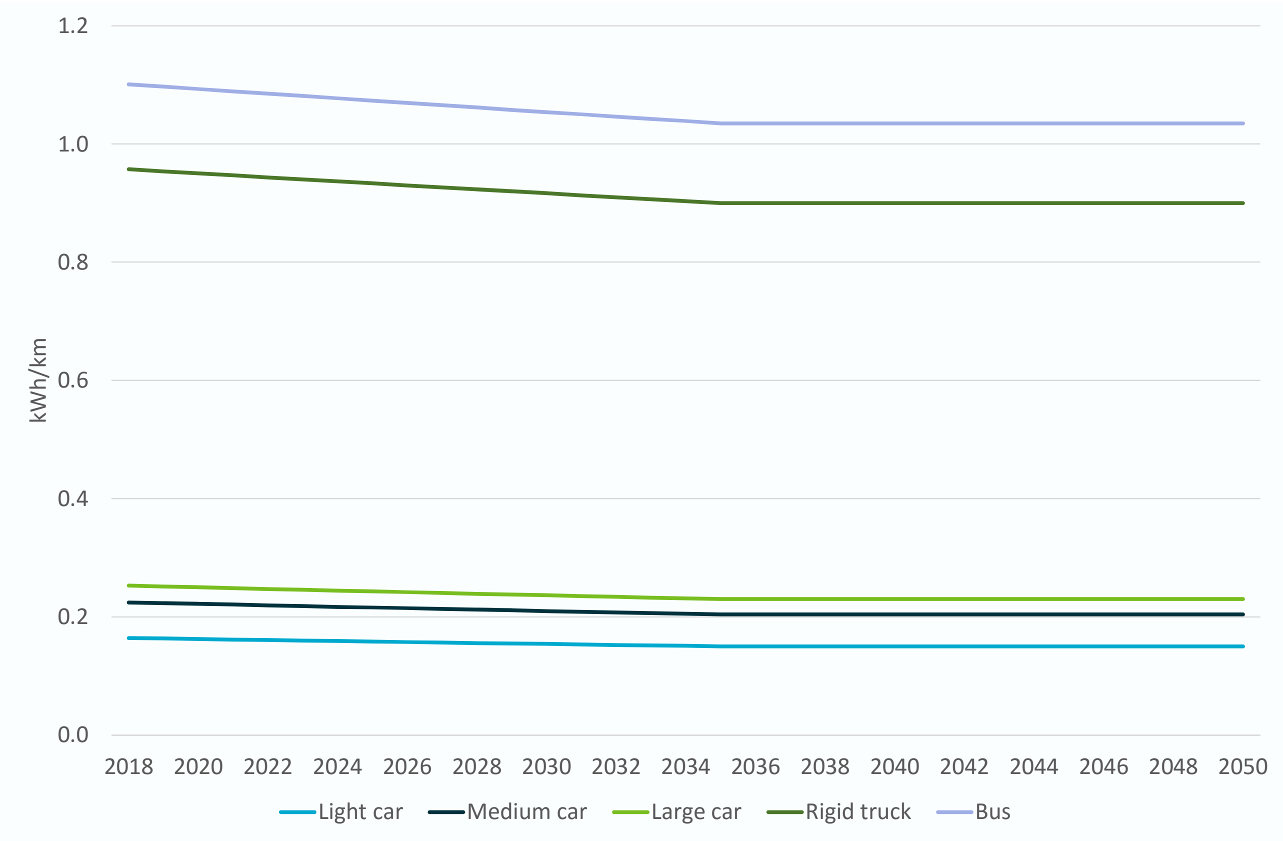
Apx Table A.2 Battery storage performance assumptions

Characteristic	Assumption
Round trip efficiency	85%
Maximum charge or discharge of rated capacity	95%
Rated capacity	Large residential: 14kWh, otherwise: 7kWh Commercial: approximately 140% the solar capacity which itself is set at proportional to average daily peak demand
Maximum power in kW	Rated capacity divided by 2.6
Degradation rate	1% per annum
Life	5000 cycles or 10 years, whichever occurs sooner.

[20] https://pvoutput.org/

A.1.3 Electric and fuel cell vehicles

The key performance characteristic for electric and plug-in hybrid electric vehicles is their fuel efficiency. Figure A.1 shows the assumed vehicle fuel efficiency per kilometre by mode for electric vehicles.



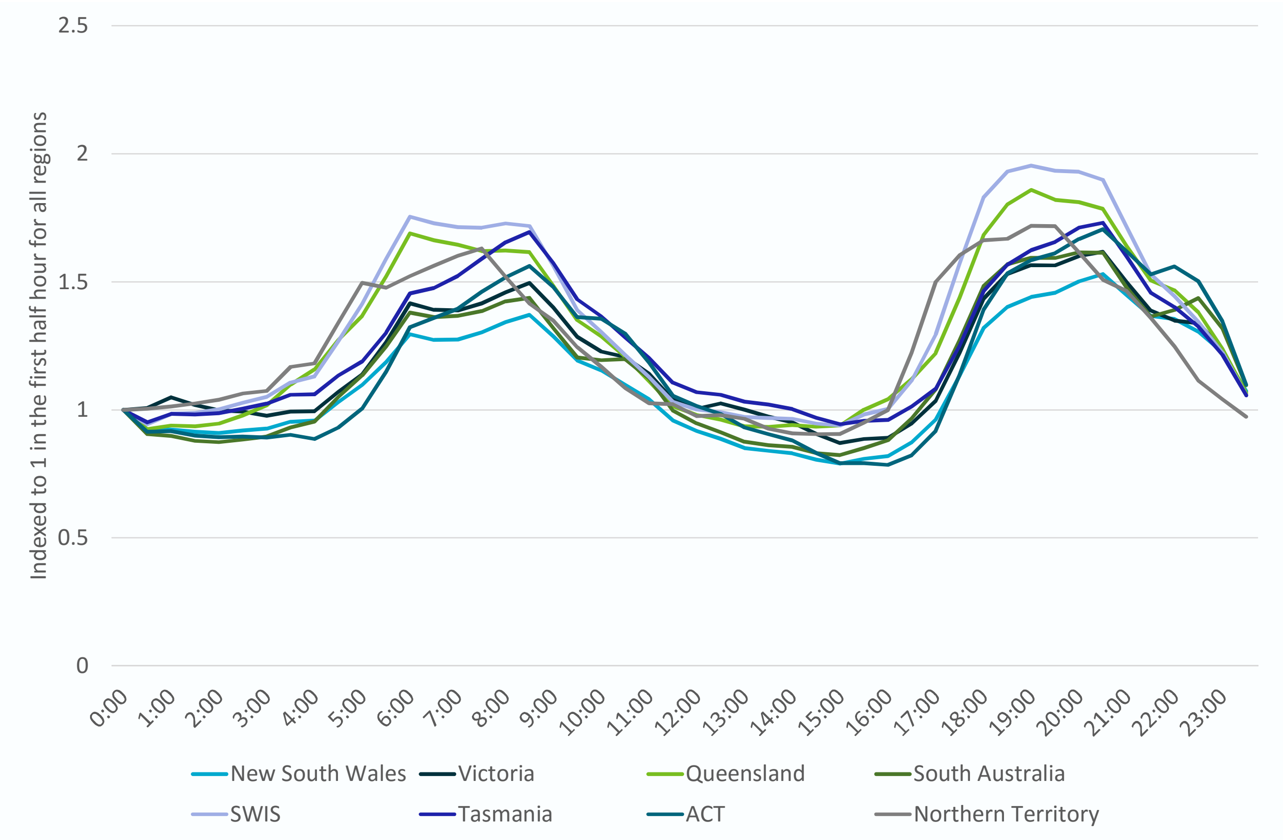
Apx Figure A.1: Electric vehicle fuel efficiency by road mode

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 of course add to total vehicle weight and we assume some improvement in battery energy density over time leads to a steady improvement in fuel efficiency up to around 2035 and plateaus thereafter. Historically, internal combustion engine fuel efficiencies have tended to plateau unless there is significant fuel price pressure (with engine improvements traded off for better acceleration or more comfort, safety and space). We assume electric vehicles will follow the same trend.

A.2 Customer load profiles

Australia still faces difficulty in accessing public load profiles due to privacy considerations. For that reason we use a mixture of synthetic and real customer load profiles. For residential data we started with around 5000 New South Wales Ausgrid profiles from the Smart Grid Smart Cities program and found the 5 most representative profiles and their ten nearest neighbours using clustering analysis. We then synthetically created 50 profiles for each other distribution network area by subtracting the difference between the most residential zone substation in each network relative to Ausgrid's most residential zone substation. This process should adjust for differences in timing (daytime hours) and climate but is probably insufficient to account for all differences in gas versus electricity use, for example, between different states. The SGSC data set did include people with and without gas and with and without hot water control but the proportions won't match other states. The average summer profile for each region is shown in Figure A.2. The non-daylight savings regions of the SWIS, Northern Territory and Queensland are evident in the differences in timing of demand. The main difference in load is that New South Wales stands out as the least extreme profile reflecting its relatively milder weather than either the northern or southern states. Otherwise they follow the same double peak/trough trend reflecting day time activity and sleep cycles. One more notable difference is the timing of controlled hot water at night in South Australia and the Australian Capital Territory.

For commercial load profiles we use a small number from previous work and do not adjust them by region. In using a smaller set our assumption is that commercial profiles vary less than residential between customers and regions.



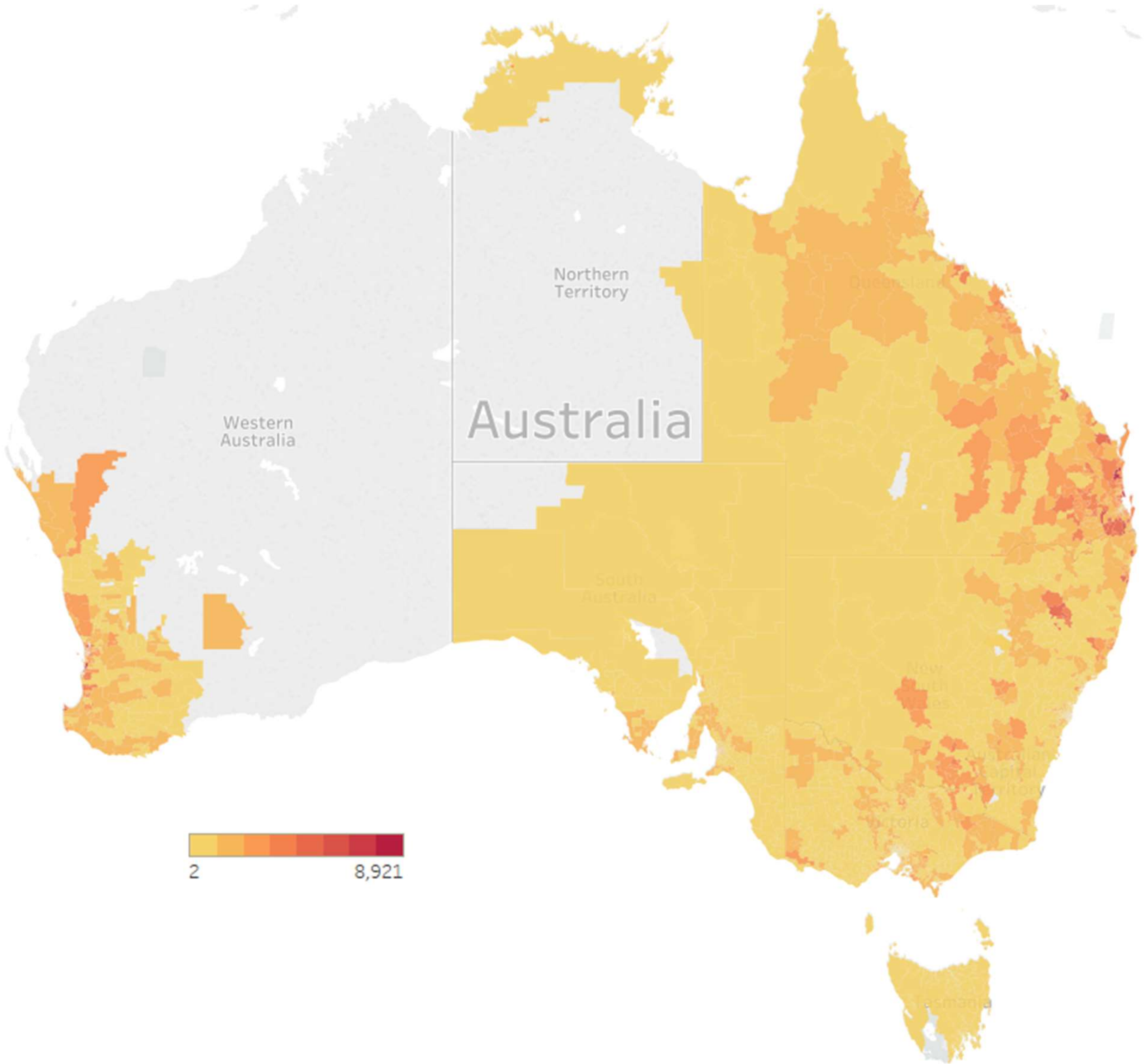
Apx Figure A.2: Index of average half hourly residential summer loads by region

Appendix B Postcode level results

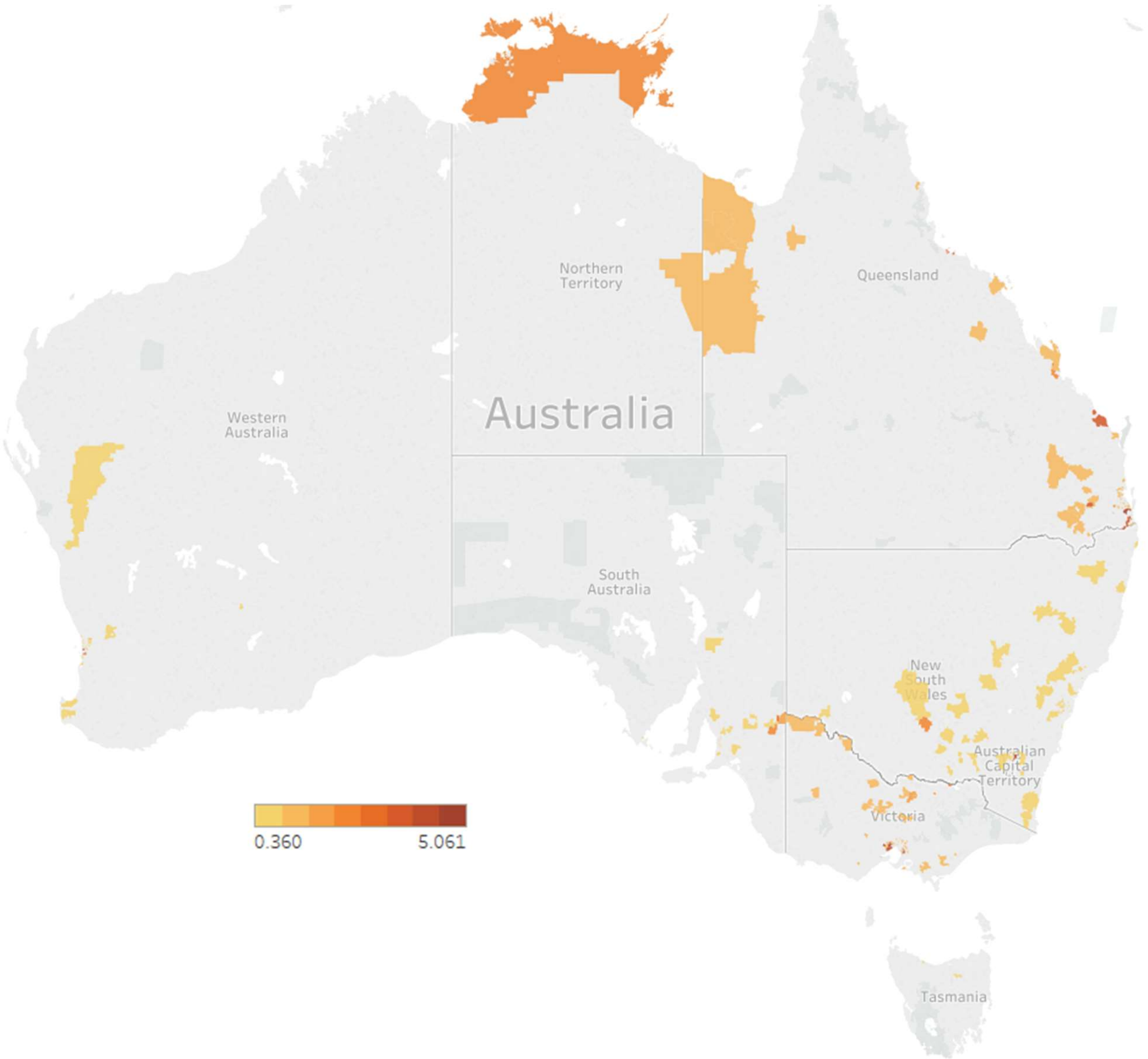
While the focus of this report is state, SWIS and DKIS level results, the projections are calculated at the ABS SA2 level to account for diversity of customers through demographic characteristics. This includes converting Clean Energy Regulator postcode data on solar installations to SA2 regions. When the projections are complete we convert them back to postcode and other spatial formats for reporting and checking purposes. The data is available in annual time steps, consistent with the state and territory data presented in the report body. For brevity, in this appendix we map the year 2030 only and a selection of the reporting data at the Australian level (Figure B.1 to Figure B.3).

Note that postcodes are not necessarily the ideal format for representing the true shape of the SWIS and DKIS electricity consumption zones. Postcodes are of different physical and population size. Therefore the colour intensity does not necessarily indicate density across the whole postcode but more likely indicates a high concentration exists within the largest city within that zone (particularly in relation to residential technologies, less so for large commercial solar plant). Two notable examples are Mount Isa and Broken Hill - mining towns, which due to their income, housing infrastructure and dominance of car travel are reasonably well suited to electric vehicle adoption but the large surrounding areas within the post code receive the same colouring. The Northern Territory also has a small number of geographically very large postcodes which tend to overstate the area of deployment.

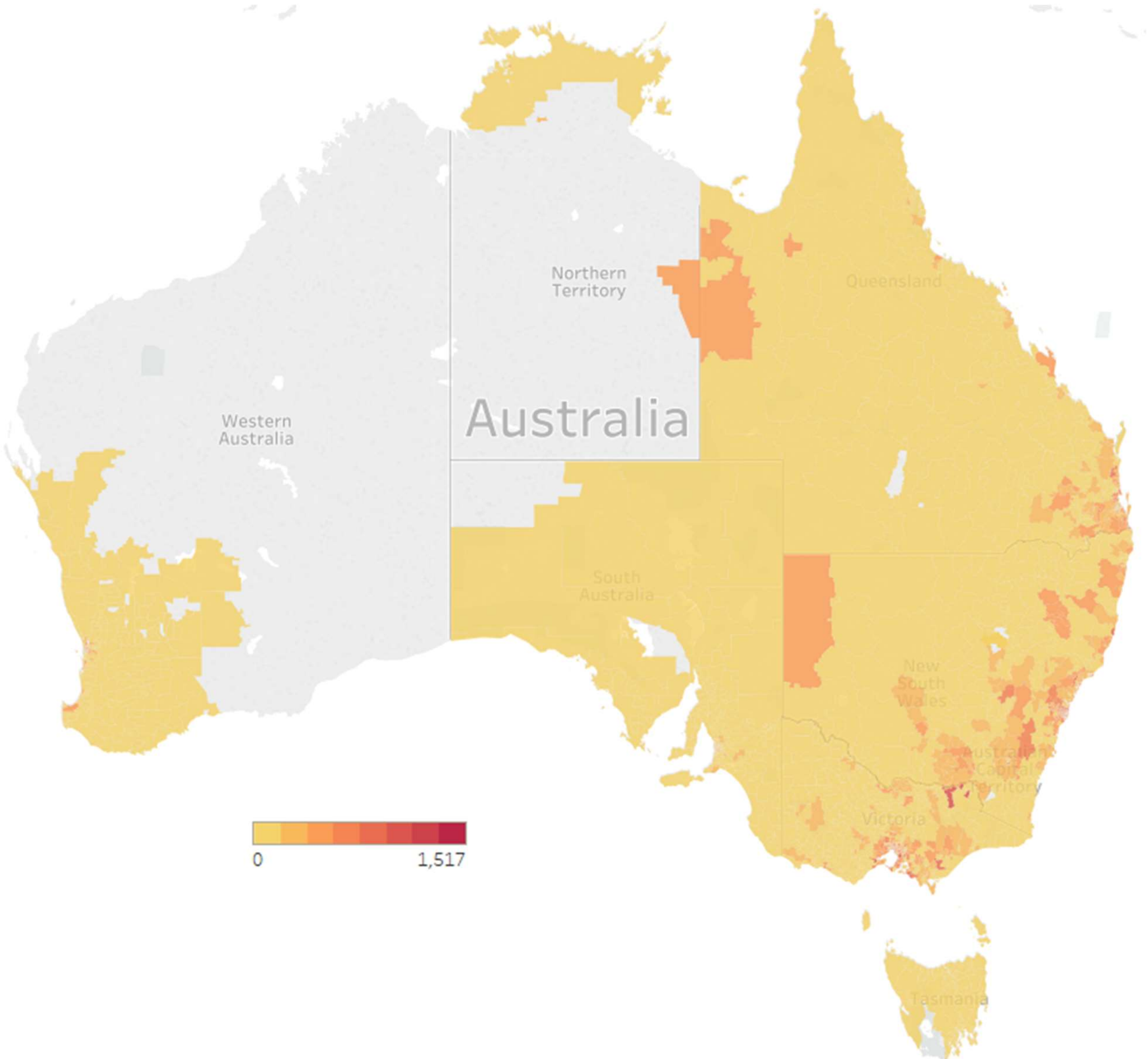
The lack of uniform population by postcode also means colour intensity is at times unreliable in representing relative shares of technology penetration with respect to residential adoption.



Apx Figure B.1: Map of the projected number of residential rooftop solar installations by postcode in 2030



Apx Figure B.2: Map of the projected capacity (MW) of commercial solar installations of size 100kW to 1 MW by postcode in 2030



Apx Figure B.3: Map of the projected number of electric or plug-in hybrid electric passenger vehicles by postcode in 2030

References

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, https://www.aihw.gov.au/reports/australias-welfare/australias-welfare-2017/contents/table-of-contents

Australian PV Institute (APVI) 2018, *Large-scale PV systems*, APVI, http://pv-map.apvi.org.au/power-stations

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

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

Brinsmead, T., Graham, P. and Qiu, J. 2017. *Economic benefits of the Electricity Network Transformation Roadmap: Technical report*, CSIRO report for the Energy Networks Australia, Australia

Cavanagh K, Ward J K, Behrens S, Bhatt A I, Ratnam E L, Oliver E and Hayward J. 2015, *Electrical energy storage: technology overview and applications*. CSIRO, Australia.

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

Commonwealth of Australia 2015, *2015 Intergenerational Report: Australia in 2055*, Canberra.

Graham, P., Reedman, L., Gargett, D. and Cosgrove, D. 2018. *Australian road revenue and expenditure: scenarios to 2050*, CSIRO and BITRE, Australia

Graham, P., Brinsmead, T., Reedman, L., Hayward, J. and Ferraro, S. 2015. *Future Grid Forum – 2015 Refresh: Technical report*. CSIRO report for the Energy Networks Association, 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

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

NSW government 2019, *Extra bill relief with solar energy and battery roll out*, NSW government, https://www.nsw.gov.au/your-government/the-premier/media-releases-from-the-premier/extra-bill-relief-with-solar-energy-and-battery-roll-out/

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 pricin*g. CSIRO, Australia

SunWiz 2019, *Australian battery market report – 2019*, SunWiz.

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

Victorian Premier 2018, *Cheaper electricity with solar batteries for 10,000 homes*, Victorian premier, https://www.premier.vic.gov.au/cheaper-electricity-with-solar-batteries-for-10000-homes/

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).

CONTACT US

t 1300 363 400
+61 3 9545 2176
e csiroenquiries@csiro.au
w www.csiro.au

AT CSIRO, WE DO THE EXTRAORDINARY EVERY DAY

We innovate for tomorrow and help improve today – for our customers, all Australians and the world.

Our innovations contribute billions of dollars to the Australian economy every year. As the largest patent holder in the nation, our vast wealth of intellectual property has led to more than 150 spin-off companies.

With more than 5,000 experts and a burning desire to get things done, we are Australia's catalyst for innovation.

CSIRO. WE IMAGINE. WE COLLABORATE. WE INNOVATE.

FOR FURTHER INFORMATION

Energy
Paul Graham
t +61 2 4960 6061
e paul.graham@csiro.au
w www.csiro.au/energy