Battery Storage and Grid Integration Program

An initiative of The Australian National University

Electric Vehicles and The Grid

Analysis, gaps, and recommendations

January 2022

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This report has been created for knowledge sharing as part of the Realising Electric Vehicle to Grid Services project.
This Project received funding from ARENA as part of ARENA's Advancing Renewables Program. The views expressed herein are not necessarily the views of the Australian Government

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Executive Summary

Australia is in the early stages of electrifying road transport, a process which is broadly seen as one necessary part of reducing greenhouse gas emissions to safer levels. Electrification is a complex process involving new technologies, infrastructures, practices, stakeholders, business models, and interactions between all of them.

This report aims to describe the current state of this landscape and recommend actions that can be taken by innovation funding bodies (such as ARENA) to enhance this uptake. Its scope includes road vehicles with plugs; charging; and enabling technology. This report does not include policy recommendations, although they are an extremely important part of the transport electrification puzzle.

Sociotechnical transitions theories provide insight into how innovation moves from niche to normality. These theories emphasise the importance of considering change across multiple dimensions and taking a socio-techno-economic approach. The report has implemented this using a mixed methods approach incorporating data, qualitative discussion, and expert feedback. As well as considering technology and cost, it also considers how users are currently, and could be, involved in creating the transport electrification future.

It is important to take a strategic approach. We have developed a framework to co-ordinate actions, shown in Figure 1. This framework is in three stages: define, build, and test.

Define refers to the fundamental basis on which transitions are built, such as who or what are regarded as important, and what settings are in place from which change can be scaled up. Policy measures (outside the scope of this report) are very important in this phase, however projects can also create definition through variation in visions and participation.

Test is technology-focused, in that it aims to cultivate and embed new solutions and avoid the creation of new problems.

Build is focused on scaling technologies—grown from good fundamentals and incorporating foresight—and ensuring that insights and lessons are shared across a very broad and diverse range of stakeholders.

Our recommended actions in each area are shown in Table 1.

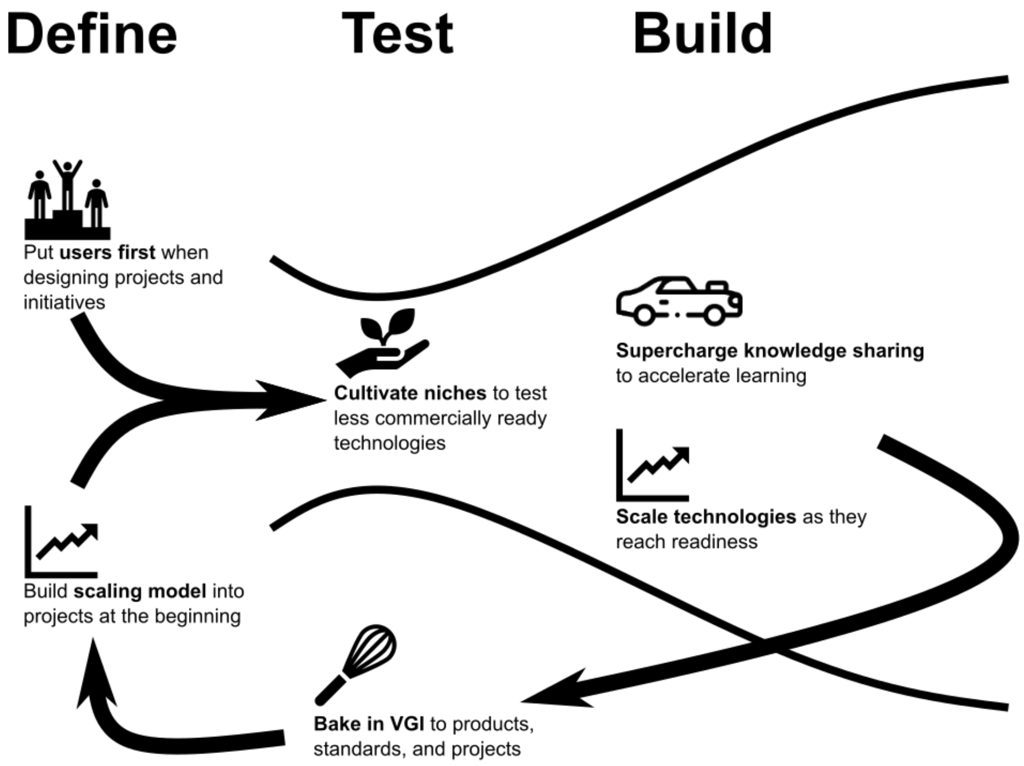


Figure 1 Recommendations framework

Table 1 Summary of recommendations

 **User first, Grid second**	**What is the recommendation?** Many existing projects have been led by, and focused on, the needs of the energy system. Projects that focus on the visions and needs of end users or localised groups have greater potential to motivate adoption.
	What does success look like? Success in this group looks like initiatives that aim to solve problems for end users, such as: • Projects that focus on hard-to-reach groups such as renters, apartment dwellers, and disabled drivers. • Projects defined by geographically contained groups such as user communities and councils. • Solutions that encourage substitution with smaller-scale transport options. • Projects that implement an agile approach and co-design solutions with users. • Inclusion of social science research in projects.

<table>
<tr>
<td rowspan="2">Scale up</td>
<td>What is the recommendation?
Technology follows a path from concept to implementation. Scaling is where technologies become part of business-as-usual. This features twice on the framework:
Before niches are developed
As technologies become ready for expansion</td>
</tr>
<tr>
<td>What does success look like?
Success in this group focuses on using trials and projects to establish the right set of fundamentals and providing support for technologies to build momentum once they mature. This could include:
For early-stage innovation
Engaging prospective financiers in innovation projects prior to starting.
Involving more transport sector stakeholders in trials, for better innovation and avoiding unintended consequences.
Encouraging greater experimentation from networks.
Building process outcomes into projects.
Scaling
Expanding infrastructures and supply chains to address known barriers to uptake, whilst also directing public funding to less viable projects (such as regional charging).
Building a clear exit path from innovation to open market funding.
Cross-organisation collaboration to remove roadblocks and encourage uptake.</td>
</tr>
<tr>
<td rowspan="2">Cultivate niches</td>
<td>What is the recommendation?
Niches are protected environments that enable testing of technologies. Importantly, how niches are defined and what is tested in them strongly influences how technologies are taken up (or are not taken up).</td>
</tr>
<tr>
<td>What does success look like?
Success in this group looks like diverse niches being tested that address existing gaps in EVs availability and adoption. A number of vehicle types, especially specialised non-freight carrying vehicles, heavy freight and buses, have negligible uptake of zero emissions technology to date. Equally, however, there is uncertainty regarding what technology (usually between hydrogen fuel cell and EV) is fit for different purposes. Projects are needed to test the gamut of implementation factors and reduce uncertainty for potential users. This could look like:
Projects devised in partnership with organisations that are potential users, such as councils, public transport agencies and logistics companies.
Systematic infrastructure planning for logistics or public transport.
Agile approaches to project design.</td>
</tr>
</table>

 **Supercharge knowledge sharing**	**What is the recommendation?** Knowledge sharing is the most important part of innovation projects (like those funded by ARENA). Current knowledge sharing for ARENA funded projects may be missing a significant portion of stakeholders (particularly those outside of the energy industry) who stand to benefit from learning from these projects.
	What does success look like? Success in this is described in two streams: translation and open data. **Translation** means bridging the gap between knowledge and action through the analysis and communication of project data. Because EVs and VGI involve technical, economic and social dimensions, it is essential that translation efforts are fluent in these fields, up to date with the most pressing questions, and able to deal with their complex interactions. A robust approach to knowledge translation would also consult stakeholders directly on their most important challenges and opportunities, and draw on international research and experience. **Open data** means cultivating an accessible and trusted data resource that services the EV landscape in Australia and works towards filling data gaps. For example, vehicle usage and charging data is not generally available outside opaque facts and figures quoted in reports. An open data resource allows users to generate insights that are relevant to their own innovation and research needs, and to be confident they are reliable. Data needs curation and to contain metadata to be useful, but the sort of data required depends on the use case.
 **Bake in VGI**	**What is the recommendation?** Vehicle Grid Integration (VGI) is expected to be needed in the future, regardless of the electrification journey. All EV projects should include consideration of the most appropriate VGI, which can then be implemented, to avoid creating problems. Charging infrastructure projects in particular could benefit from this approach
	What does success look like? Success in this initiative is when appropriate VGI is provided “standard” in products in the Australian market. In the short term this requires trialling VGI in more contexts and assessing the customer interface of this VGI.

1 Introduction

1.1 Background and purpose

Australia is in the early stages of electrifying road transport, a process which is broadly seen as one necessary part of reducing greenhouse gas emissions to safer levels. Electrification is a complex process involving new technologies, infrastructures, practices, stakeholders, business models, and interactions between all of them. One key aspect of this is the question of grid integration of electric vehicles. Although some argue that the electrification of at least light passenger transport is to a certain degree inevitable, the speed, form and extent of the transition remains uncertain, which complicates grid integration. As a result, trials and new technology projects are an essential part of understanding, experimentation, planning and implementation.

This report aims to analyse the current state of road transport electrification and grid integration in Australia across multiple dimensions in order to inform future demonstration and commercialisation projects. It takes a socio-techno-economic perspective in that, firstly, it considers the multi-levelled nature of transitions [1], and secondly, it considers not just the technical challenges but also end-users and how they participate in co-creating the future. The report adopts mixed methods incorporating data, qualitative discussion and expert feedback to identify gaps and form recommendations intended for funding agencies.

Introducing the Realising Electric Vehicle-to-grid Services (REVS) trial

This report has been developed as part of the REVS trial. In an Australian first, the Realising Electric Vehicles-to-grid Services (REVS) project demonstrates how commercially available electric vehicles (EVs) and chargers can contribute to energy stability by transferring power back and forth into the grid, as required.

EVs will inject power back into the grid during rare events (to avoid possibility of blackouts) and EV owners will be paid when their vehicles are used for this service.

Employing 51 Nissan LEAF EVs across the ACT as part of the ACT government and ActewAGL fleet, the REVS project seeks to support the reliability and resilience of the electricity grid, unlocking economic benefits making electric vehicles a more viable and appealing transport option for fleet operators.

The REVS consortium covers the whole electricity and transport supply chains including ActewAGL, Evoenergy, Nissan, SG Fleet, JET Charge, ACT Government and the Australian National University. Together the consortium will produce a roadmap with recommendations that will accelerate the deployment of V2G nationally.

The project has been endorsed by the Australian Renewable Energy Agency (ARENA) and has received funding as part of ARENA's Advancing Renewables Program.

REVS is underway and will publish a final report in late 2022.

https://secs.accenture.com/accenturems/revs/

1.2 Scope

The scope of this report is limited to technical, economic and social aspects of road transport electrification and grid integration. It is limited to battery electric vehicles (EVs) with plugs, of all vehicle classes ranging from light to heavy. The report also mentions other associated technologies and infrastructures such as hydrogen fuel cell vehicles and public transport where they are of relevance. It is also limited to road transport, therefore excluding other modes such as aviation or shipping and specialist vehicles such as those used in mining and agriculture.

It must also be noted that this report is limited to projects such as trials and does not extend to policy issues. The policy response required for transport decarbonisation is by far the most important role of governments. Projects alone cannot achieve the change required, and therefore the recommendations herein should be considered just one part of vehicle grid integration (VGI). For a recent review of Australian policy options, we direct readers to transportfacts.org.

The report will review the following issues with reference to transitions and commercial readiness:

- Road vehicles of different classes,
- Charging and grid integration technologies, including managed charging (V1G), vehicle to grid (V2G) and others,
- Grid services and enablers,
- Partners to VGI projects and their visions, including community and market-driven approaches,
- End-user sectors such as fleets, private users, freight, and others,
- Participation models for VGI projects.

1.3 Energy and transport transitions

Transitions toward more sustainable ways of living are explained by theories such as the multi-level perspective [1], which explains how long-term change and new innovations can alter society. The multi-level perspective describes change as occurring through processes interacting at three different levels: niches, regimes and landscapes, as shown in Figure 2.

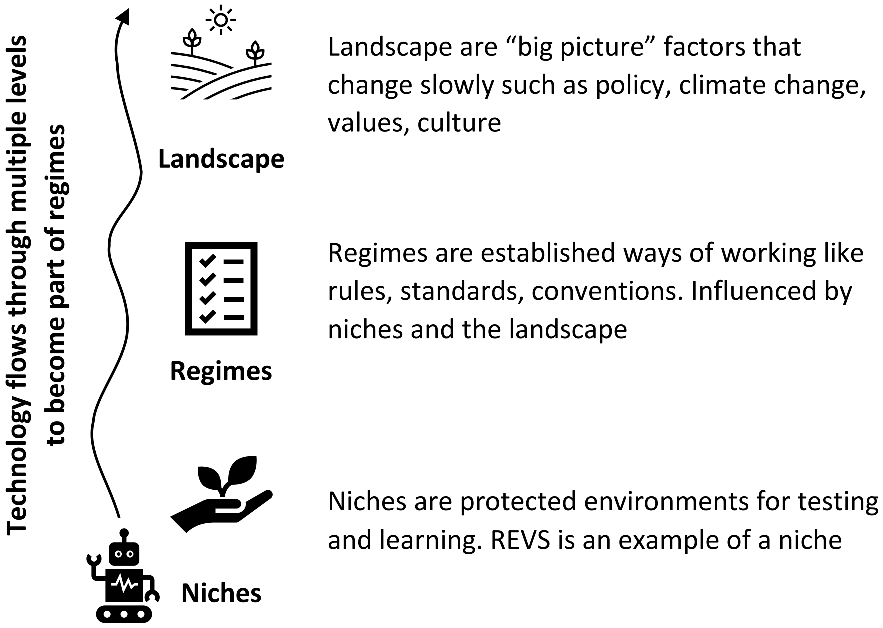


Figure 2 Multi-level perspective

Existing systems with established ways of doing—for example, the vehicles, conventions of private ownership, engine technology, refuelling stations, road rules, standards and so on that make up automobility—are called regimes. Transitions are essentially the process of regime change, either by regimes adapting themselves, or being disrupted by innovation and outside pressure.

Regimes are influenced by the bigger picture, or landscape, which represents the structural, long-term trends which exert pressure on regimes. Landscape-level changes are large and beyond the control of individuals. Examples include climate change and climate change policy, urban form, societal values, digitalisation, or more sudden pressures such as those arising from the coronavirus pandemic or global financial crisis.

At the smallest scale, niches are protected spaces for novelty and innovation. Niches can gain momentum, influence and change regimes. A good example of this is electric vehicles, which after many years of development have stabilised into a dominant design, gained legitimacy, and are now being produced by most or all major auto manufacturers.

This report aims to reflect the multi-level perspective of transitions by examining Australia’s current road transport regime with regard to electrification, and describing the trends and activities that can influence this regime, at both the large and small scale.

1.3.1 Nurturing niche innovations in vehicle grid integration

Vehicle grid integration can be considered a family of related niche-level innovations that are related to innovation in both EVs and distributed energy resources (DER). Niches can be nurtured by focusing on three important, interlinked processes of niche development [2]:

- **Learning**, which includes both problem-solving towards a known goal (first-order learning) and the questioning of assumptions leading to a change in expectations and goals (second-order learning).
- **Network development** of a constituency driving a new technology that includes users, producers and regulators and whose semi-coordinated actions can bring about a shift.

- **Expectation building**, which is the development of stable, shared conceptions of a niche in order to build coalitions, generate urgency and grow cultural legitimacy.

The ARENA model focuses heavily on all of these fronts through its knowledge and innovation work, including Knowledge Bank, A-Lab and the Distributed Energy Integration Program (DEIP). VGI, however, involves not just the energy system but the transportation system too, creating new opportunities and challenges for collaboration and new ways for Australian people and companies to not only become involved in the transition, but to influence the direction it takes.

With the new involvement of the transport sector in the energy transition (and vice versa) efforts should be redoubled in knowledge sharing, collaboration, and bringing different perspectives into technology development and innovation. This will be reflected in the recommendations.

1.3.2 Second-order effects and unintended consequences

It is important to acknowledge that innovations are not universally “good”, even when they are part of sustainable transitions. A shift to EVs, while reducing emissions, may entrench and lead to greater reliance on private vehicles [3] and its associated negative impacts on road congestion, noise, urban heat islands, land use and so on. Further in the future, shifts to autonomous vehicles could undermine public transport as some research has suggested [4]. For this reason, it is essential that stakeholders outside of the energy sector – such as urban planners, sustainability experts and communities – are involved in leading transition activities. We have included some of these stakeholders in our engagement as part of developing this report, but this can only be considered the start of this journey.

Similarly, transitions have the potential to reproduce and exacerbate inequalities. As will be discussed later in this report, Australian VGI projects have largely left out renters and people without off-street parking, and EV infrastructure is being built without standards for disabled access. The energy sector is neither equipped nor necessarily motivated to deal with these issues, hence a greater range of stakeholders needs to participate.

2 Approach

The electrification and grid integration landscape is diverse and complex, involving change at different scales and speeds as well as a great deal of uncertainty about what ought to be done. This report aims to make sense of this complexity by asking where Australia needs to be in terms of transport electrification towards the reduction of greenhouse gas emissions; estimating how far away Australia currently is; examining what has been done locally to date, and what the most pressing gaps are. The first part of this approach therefore takes a “top-down” perspective looking at the needed transition of the vehicle fleet, and the second part is a “bottom-up” perspective of the trials and projects that are completed or underway (Figure 3). This chapter outlines the data sources and methods used in each section of the report.

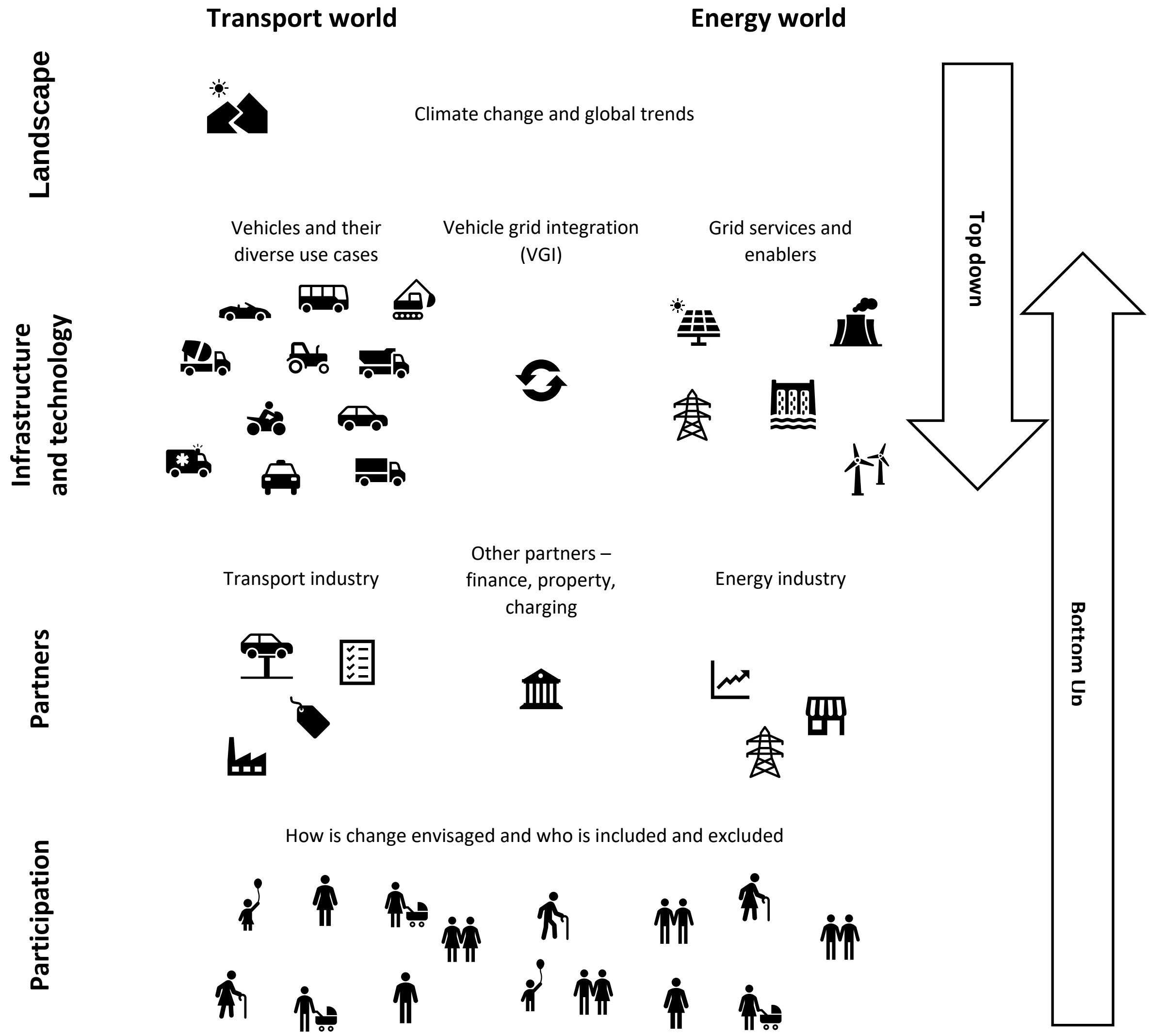


Figure 3: Combining top-down analysis (examining where Australia is and needs to be) with bottom-up analysis (of what has been trialled in Australia so far).

2.1 Top-down analysis

The first section of the report begins by examining road transport electrification and grid integration with a landscape-level view of global change across energy and transport. A literature review of relevant climate change plans and policies is used to locate where Australia should be in terms of transitioning different vehicle classes in the coming years. Following this, we review and discuss the key drivers and constraints in the energy and transport transition in Australia.

The remaining parts of the top-down analysis focus on vehicle, grid, and grid integration technology. These form an opportunity assessment that aims to survey progress across the different technologies and determine what segments are more promising or require more development. This analysis is based on statistics, reports, plans, and policies. It:

- Builds a list of areas of investigation (such as vehicle type, charger location)
- Presents the applicable taxonomy within areas (such as vehicle classes)
- Investigates the current status and impact of effort to accelerate uptake within this class.

The analysis in this section mixes qualitative and quantitative methods. Where there is data available, quantitative analysis provides numerical evidence of progress and priority areas. Qualitative analysis provides insight where public data is not available, not processed within the scope of this report, or where the factors are not quantifiable. Examples of the data that has been assessed qualitatively and quantitatively are shown in Table 2.

Table 2: Approaches used in top-down analysis of technology segments.

Quantitative	Qualitative
Statistical data Vehicle usage data	Analysis of plans, strategies, reports Commercial readiness index[1] Assessment of priority areas

2.2 Bottom-up analysis

The second analytical section aims to identify and characterise what has been done to date in terms of recent projects and trials in road transport electrification and grid integration, focusing on, but not limited to, ARENA-funded projects. This section uses participation as a framework for understanding the breadth of what is possible in terms of visions for the future and potential solutions, and cross-references with the different technology domains of transport, grid integration and energy. Key to this process is a consideration of what groups are currently left out, or likewise types of projects that are overlapping. The analysis aims to determine where Australia is currently placing efforts, what gaps this creates, and what further efforts could be made.

2.3 Forming recommendations

The top-down and bottom-up analysis was combined to identify gaps and form recommendations for directing support for future projects. A draft set of recommendations was created and tested in a series of 25 half-hour interviews with Australian and international energy and transport stakeholders so that they could be further refined. The final recommendations are presented in the report. A summary of interviewees is shown in Table 3.

[1] See https://arena.gov.au/assets/2014/02/Commercial-Readiness-Index.pdf

Table 3: Demographics of interviewees

Sector		Location		Gender	
EV Charging	4	**Australia**	23	**Men**	22
Education/Research	5	**Overseas**	3	**Women**	4
Energy	4				
Government	3				
Transport	10				
Total	**26**				

3 Top-down analysis

3.1 Landscape and global trends

The progress of EV adoption and VGI in Australia is subject to several large-scale influences that may have complementing or disruptive effects. This section outlines these to understand how they might affect the Australian transition.

Key takeaways from this section

- There is **low uptake** of EVs in Australia now – far behind other jurisdictions worldwide. But EVs form a key part of our decarbonisation journey
- EVs could cause **increasing demand**, but also promises to enhance the **flexibility** of the energy system
- There are few vehicle manufacturers in Australia therefore technology available in Australia is **strongly influenced by worldwide trends**

3.1.1 Climate change targets

Various expert bodies and Australian state governments have modelled the change in the vehicle stock required to limit global warming to manageable levels. These studies uniformly indicate that a very rapid change is required. This section summarises the change required, drawing on publications from the NSW and Victorian Governments, Infrastructure Victoria, ClimateWorks and the International Energy Agency [5]–[9].

Presently, less than 1% of Australia's new light vehicle market is electric [10]. The consensus is that at least 50% of light vehicle sales (including passenger and commercial vehicles) should be Electric Vehicles (EV) or Zero Emissions Vehicles (ZEV) by 2030 [5], [7]–[9]. At that time, the total light vehicle stock should be comprised of 15% - 28% EVs [8], [9]. Motorcycles are transitioning more quickly and can achieve 50% electric penetration by 2030 [8]. These adoption curves are summarised in Figure 4. The IEA and Infrastructure Victoria recommend that all light vehicle sales should be zero emissions by 2035 [6], [8].

In terms of heavy vehicles, the studies suggest that 25% - 59% of new trucks sold should be zero emissions by 2030 to avoid more dangerous warming [8], [9]. Public transport buses have been particularly targeted by governments, and it is proposed that all new buses in Victoria will be ZEV by 2025 [5]. The IEA foreshadows a slower transition for trucks and buses, with ZEVs reaching 59% and 79% of respective total stock [8].

In some cases, technologies other than battery EV will be most suitable for heavy vehicles. In addition, ClimateWorks recommends optimising/consolidating freight routes and switching transport modes in order to reduce emissions through better productivity [9].

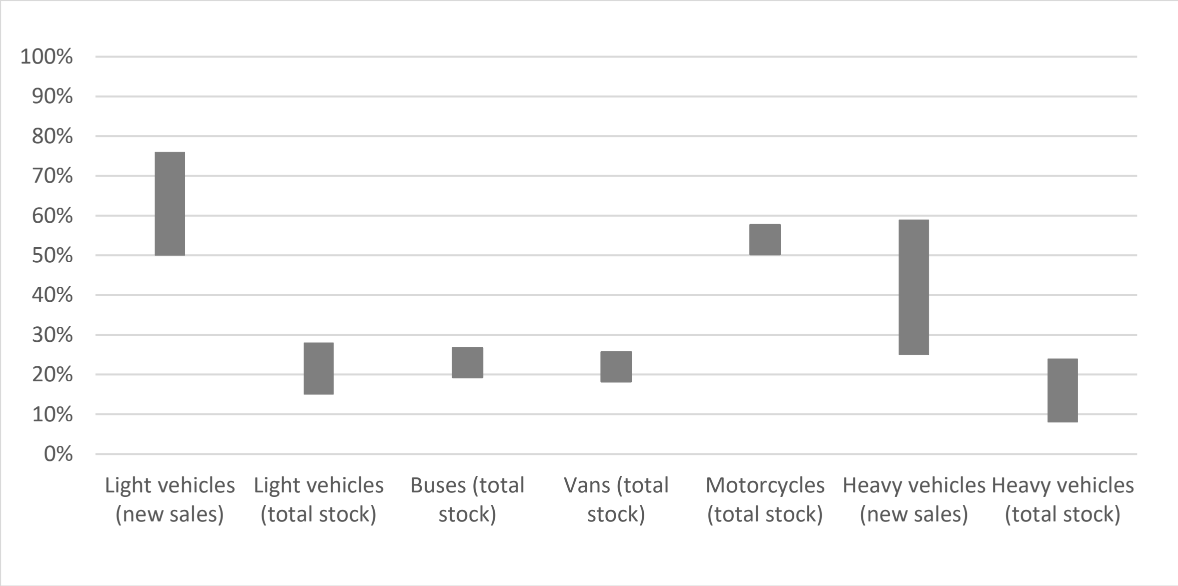


Figure 4: 2030 targets and target ranges for different vehicle classes

3.1.2 Energy transition

Driven by cost-competitive renewable energy, the retirement of old coal-fired generators and sub-national climate policies, Australia's electricity system is in a period of rapid change. AEMO has indicated that the future grid will be dominated by a diverse mix of behind-the-meter and grid scale renewable energy supported by dispatchable firming resources and enhanced grid and service capabilities [11].

En masse EV adoption represents both a new demand for electricity and a new source of a wide range of grid services, particularly at the shallow and medium scale (up to 12 hours). The scale of EV power consumption, and the flexibility of this demand, suggests that some level of VGI will be essential (discussed in 0). As a source of services, EVs represent a potentially large opportunity to facilitate the energy transition and use existing assets (discussed in 3.5).

VGI technologies are at varying stages of development in being able to provide different solutions and services. They depend on system rules, linkages, costs, and reasons why EV owners might participate in VGI. The necessity of VGI will vary depending on the local grid – for example, one study of EV charging in distribution networks found that some existing networks were able to host an EV penetration of 80% without VGI measures, whereas other networks could be expected to encounter problems at up to 20% penetration. Rural networks generally had lower capacity to accommodate EV charging than urban networks [12]. Due to Australia's size there are many rural networks therefore these issues may be felt more keenly than other jurisdictions (such as UK).

3.1.3 Automotive transition

Most Australian vehicles are imported although niche manufacturers remain. This makes global trends particularly important push factors for Australia. Globally, automakers are trending towards electrification, with many now seeing it as crucial to competitiveness and consequently are making significant investments and commitments. As a result, Australia's local vehicle market is influenced by the carbon reduction policies of other governments. This external influence means that our Infrastructure, rules, technology development and participation frameworks need to catch up.

Australia, however, has not implemented the types of fuel and efficiency standards that favour EV uptake in other countries, which means there is an absence of disincentives to sell lower-efficiency vehicles to the Australian market. Similarly, policies that reduce the capital cost to purchase an EV are of modest impact (in terms of savings to buyers) and administered at the State and Territory level, making them fragmented.

3.2 Vehicles

Transport electrification is in its early stages. As of January 2021, there were over 20.1 million registered motor vehicles in Australia, of which less than 1% were electric [13]. Vehicles fit a variety of forms, functions, and purposes. This chapter aims to analyse Australia's current vehicle stock to determine the gaps and opportunity areas.

We examined statistics on vehicles in Australia and how they are used. This tells us at a high level which classes may be more beneficial to transition to zero emissions due to their relative impact, and relative progress towards decarbonisation. It is important to note that vehicle classes discussed here are very broad. Within each class there is significant diversity in vehicle type and use cases. For example, the needs of a taxi differ significantly to that of a private vehicle, although both are passenger vehicles.

Key Takeaways from this section

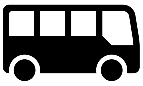
- **Passenger vehicles** are the highest impact class of vehicles, and the most developed
- **Motorcycles** are promising because they are close to price parity with internal combustion engine vehicles and potentially can reduce congestion
- **Heavy vehicles** (trucks, articulated trucks) have low uptake of electric vehicles and high emissions per vehicle
- **Buses** have momentum to uptake, and similar substitution benefits to motorcycles

3.2.1 Vehicle classification

Vehicles have a broad diversity of classes, ranging from motorcycles to large trucks. This chapter considers vehicles by class as defined by the Australian Bureau of Statistics and shown in Table 4. The composition of the Australian vehicle stock by class is shown in Figure 5.

Table 4: ABS classes of motor vehicle [13]

Class	Description
 **Passenger vehicles**	Motor vehicles constructed primarily for the carriage of persons and containing up to nine seats (including the driver's seat). This category includes cars, station wagons, four-wheel drive passenger vehicles and forward-control passenger vehicles. Campervans are excluded.
 **Motorcycles**	Two and three wheeled motor vehicles constructed primarily for the carriage of one or two persons. This category includes two and three wheeled mopeds, scooters, motor tricycles and motorcycles with sidecars.

Class	Description
 [2] **Light commercial vehicles**	Vehicles primarily constructed for the carriage of goods, and which are less than or equal to 3.5 tonnes GVM. This includes utilities, panel vans, cab-chassis and forward-control load carrying vehicles (whether four-wheel drive or not).
 **Rigid trucks**	Motor vehicles of GVM greater than 3.5 tonnes, constructed with a load carrying area. This includes trucks with a tow bar, draw bar or other non-articulated coupling on the rear of the vehicle.
 [2] **Articulated trucks**	Motor vehicles constructed primarily for load carrying, consisting of a prime mover having no significant load carrying area, but with a turntable device which can be linked to one or more trailers.
 **Non-freight carrying trucks**	Specialist motor vehicles or motor vehicles fitted with special purpose equipment, and having little or no load carrying capacity (e.g. ambulances, cherry pickers, fire trucks and tow trucks).
 **Buses**	Motor vehicles constructed for the carriage of passengers. This category includes all motor vehicles with 10 or more seats, including the driver's seat

[2] Icons courtesy of Freepik from www.flaticon.com

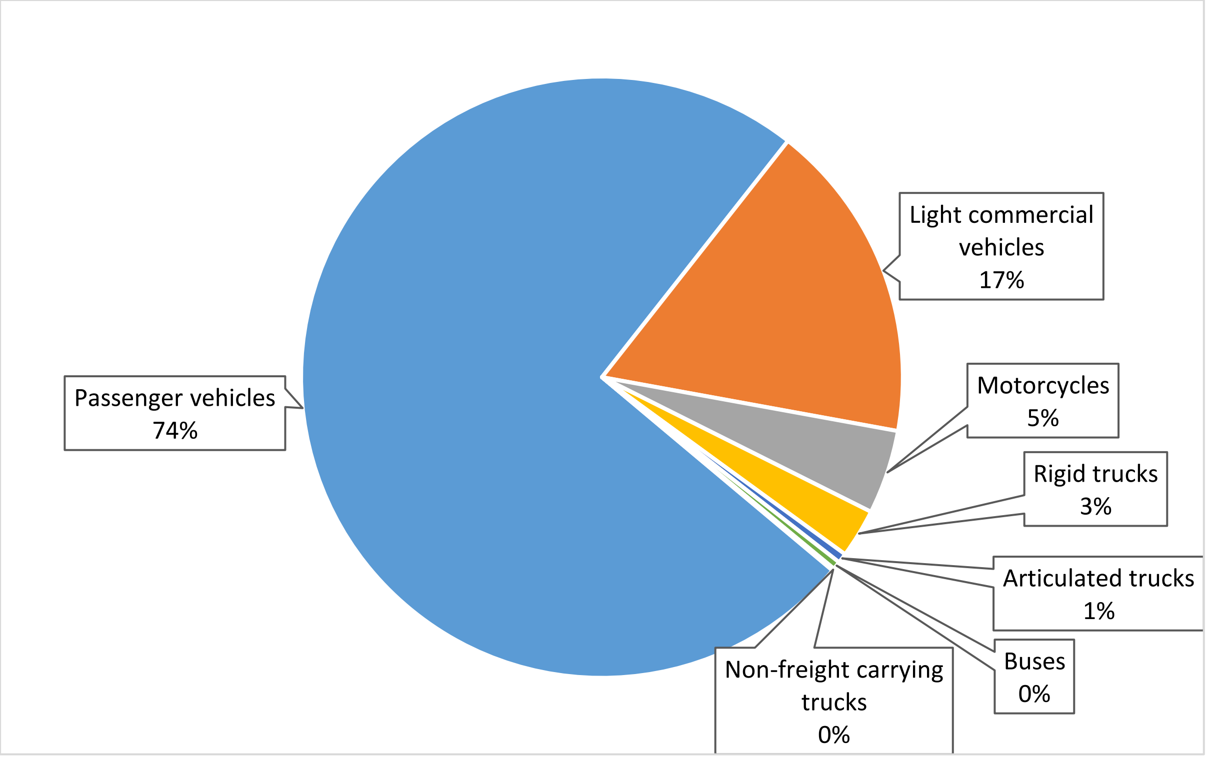


Figure 5: Composition of Australian vehicle stock by vehicle class [13]

EV uptake amongst these segments is uniformly low. Figure 6 shows uptake across the classes, clearly illustrating the scale of the electrification challenge. Most of the uptake is across the lightest vehicles (passenger vehicles and motorcycles). All other classes apart from articulated trucks have some uptake, albeit very small.

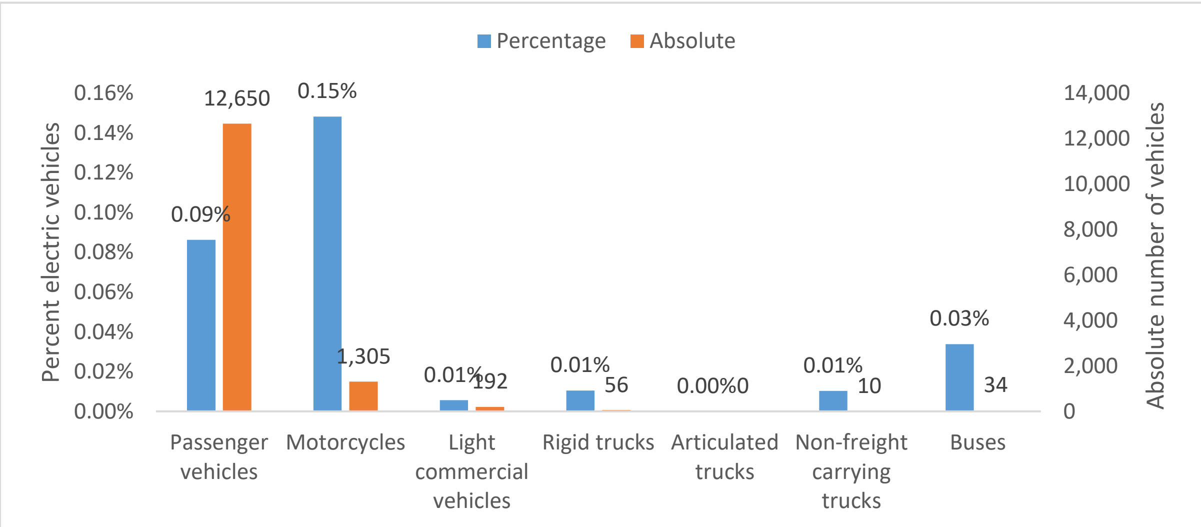


Figure 6: EV uptake across vehicle classes [13]

3.2.2 Electric vehicle availability and commercial readiness

A major inhibitor of EV adoption is the availability of suitable vehicles at an appropriate price. This section will detail what is currently available to potential adopters.

For zero emissions vehicles there are currently two fuel types under consideration: battery electric and hydrogen. For most classes (except for articulated trucks), there are more battery electric vehicles available within the segment.

This report focuses on battery electric vehicles. Its aim is to span the energy/transport nexus, which is more relevant for battery electric vehicles because they rely on energy infrastructure to provide their energy needs at the time and place of charging. Hydrogen vehicles, on the other hand, use a more conventional fuelling method that is less reliant. Although there may be significant grid services capability from hydrogen electrolysers it is not in the scope of this project. Hydrogen vehicles are mentioned where relevant.

Passenger vehicles

There are an increasing number of electric passenger vehicles available today. The EV Council reported that there were 31 models available in Australia in 2021 [14], while in 2020 there were 28 [15]. This is reflective of a growing market but still behind other jurisdictions; for example, there are over 130 fully or partially electric models available in the UK [16].

EVs still come at a price premium compared to their internal combustion counterparts. Although models are not always directly comparable due to differences in standard features, an indication of the remaining gap is shown in Table 5. EVs are cheaper to run, which can close this gap significantly. The economics for an individual use case depend on its driving patterns and the energy cost compared to the combustion fuel costs. Breakeven distance based on energy costs only, as shown in Table 5, remains around 200,000-250,000 km over the lifetime of the vehicle.

While the new market for vehicles is increasing, there are still few used electric vehicles available. At the time of writing of this report, carsales.com.au lists over 35,000 used diesel and petrol-fuelled vehicles available in Victoria, but only 35 electric (0.1%)[3]. There is work to increase this supply through importing vehicles from overseas (such as The Good Car Company[4]). Similarly, initiatives to encourage fleet uptake increases used vehicle supply as these vehicles are cycled from fleets [17].

Table 5: Pricing for selected electric and comparable internal combustion vehicles

Manufacturer and model	Price: Internal Combustion Engine	Price: Electric	Electric premium	Approximate breakeven drive distance[5]
MG ZS	\$21,990[6]	\$44,990[7]	\$23,000	228,352 km
Hyundai Ioniq	\$45,440[8]	\$54,415[8]	\$8,975	202,104 km
Mini	\$42,564[9]	\$61,479[9]	\$18,915	238,143 km[10]

[3] https://www.carsales.com.au/cars/used/victoria-state/ (accessed 10/11/2021)
[4] https://www.goodcar.co/ (accessed 10/11/2021)
[5] Calculated using Combined cycle fuel efficiency (l/100), WLTP combined cycle range (km), EV battery capacity (kWh), Average Melbourne metro fuel prices as per https://www.racv.com.au/on-the-road/driving-maintenance/fuel-prices.html (accessed 10/11/2021), and powershop "super off-peak" EV charge plan as per https://www.powershop.com.au/app/rates/victoria/electricity/residential/ev/ausnet/combined-all.pdf?v=1.1.0 (accessed 10/11/2021)
[6] https://mgmotor.com.au/models/mg-zs/ (accessed 10/11/2021)
[7] https://mgmotor.com.au/models/mg-zsev/ (accessed 10/11/2021)
[8] https://www.hyundai.com/au/en/cars/eco/ioniq (accessed 10/11/2021)
[9] https://www.mini.com.au/configurator (accessed 10/11/2021)
[10] Efficiency data from https://www.drive.com.au/compare-specs/#compare[498726,498629] (accessed 10/11/2021)

Overall, the CRI is assessed at **4: Multiple commercial applications**. For passenger vehicles the largest challenges are encouraging uptake and reducing cost differential.

Successes	Gaps
• Increasing availability of vehicles • Standardisation of performance information	• Price premium • Poorly developed second-hand market • Availability of supporting infrastructure • Industry supply chain and skills

Motorcycles

Motorcycles vary greatly in size and performance. Smaller electric motorcycles such as scooters are a low cost and flexible form of transport for city dwellers. The price gap for electric motorcycles can be small or negligible. For example, the Fonz Arthur is advertised at $3,990[11] while the Honda MW110 Benly small ICE-engine scooter is advertised at $4,541[12]. Electric performance motorcycles are beginning to become available, such as the Harley Davidson Livewire which at $49,995[13] is still significantly more expensive than similar internal combustion engine bikes from the same manufacturer. For example, the Harley Davidson Sportster-S is advertised at $26,495[14].

There are examples of larger-scale deployment in this class. For example, Australia Post has integrated 2,100 Kyburz 3-wheeled delivery vehicles and 2,500 electric bicycles into their fleet since 2017 [18].

Unregistered e-bikes and e-scooters overlap with small, registered scooters [19]. These light vehicles are seeing increasing popularity amongst commuters who may previously have had difficulty using pedal bicycles [19], but along with motorcycles, they also have potential to substitute for passenger vehicle travel. Worldwide, mode shift to lighter or shared transport is a centrepiece of strategies to reduce emissions. For example, transport plans in the Australian Capital Territory [20] and London [21] both state plans to encourage mode shift from single-occupancy vehicles to active and micro modes of transport such as e-bikes.

Overall, the CRI for motorcycles is assessed at **4: Multiple commercial applications**. There are vehicles available, although relatively few from established manufacturers.

Successes	Gaps
• Vehicles close to cost competitive • Potential for mode shift from passenger cars	• Low availability from established manufacturers • Industry supply chain and skills

Light commercial vehicles

The light commercial vehicle class consists of vans and utility vehicles. Electric vehicles are beginning to become available in this segment. Vans include the Renault Kangoo Z.E[15] small delivery van or the SEA Electric conversion of the Ford Transit [16]. More have been announced, particularly utilities

[11] https://www.fonzmoto.com/product/arthur (accessed 10/11/2021)
[12] https://motorcycles.honda.com.au/models/onroad/scooter/mw110-benly, price for Melbourne, Vic (Accessed 10/11/2021)
[13] https://www.harley-davidson.com/au/en/motorcycles/livewire.html (accessed 10/11/2021)
[14] https://www.harley-davidson.com/au/en/motorcycles/sportster-s.html (accessed 10/11/2021)
[15] https://www.renault.com.au/vehicles/kangoo-ze/ (accessed 10/11/2021)
[16] https://www.sea-electric.com/products/transit-ev/ (accessed 10/11/2021)

(utes), such as the Tesla CyberTruck[17] and Rivian R1T[18] although it is unclear when they might become available in Australia. ACE-EV aims to manufacture small delivery vans and utilities in Australia[19]. There is still a significant price premium for electric vehicles in this segment. The Kangoo Z.E., for example, is advertised at $55,091 with an electric engine and $29,709 with a diesel ICE engine[20].

Overall, the CRI is assessed at **3: Commercial scale-up**. Vehicles are becoming available but are yet to see significant penetration in the market.

Successes	Gaps
• Several models available on the market	• Few current examples of larger-scale deployments • Availability of supporting infrastructure • Industry supply chain and skills

Rigid trucks

Rigid trucks are a diverse group of non-articulated vehicles over 3.5T GVM. There are growing examples of electric vehicles available in this class. SEA Electric for example primarily provides vehicles in this class, with a diverse range of available drivetrains[21]. Other new entrants, such as Nexport[22] are also importing vehicles into Australia. Similarly, established manufacturers, such as Volvo[23] are offering electric versions of their traditionally diesel vehicles. Public pricing information is difficult to locate for vehicles in this class due to the diversity on body styles and specifications, few available models, and low uptake.

Some organisations have begun to integrate electric trucks into their fleets. These are more commonly the larger fleet organisations such as Linfox [22], and Australia Post [23].

There are fewer hydrogen vehicles available in this class, however there are vehicles under development. For example, Hyundai have announced a strategy to use hydrogen fuel-cell vehicles in the transport sector[24].

Overall, the CRI is assessed at **2: Commercial trial, small scale**. Vehicles are becoming available but still have niche or demonstration use cases.

Successes	Gaps
• Some vehicles are beginning to become available	• Price premium • Few current examples of larger-scale deployments • Availability of supporting infrastructure • Industry supply chain and skills

[17] https://www.tesla.com/en_au/cybertruck (accessed 10/11/2021)
[18] https://rivian.com/r1t (accessed 10/11/2021)
[19] https://www.ace-ev.com.au/ (accessed 10/11/2021)
[20] https://www.renault.com.au/build-and-price/build/select-vehicle/ (accessed 10/11/2021)
[21] https://www.sea-electric.com/products/ (accessed 10/11/2021)
[22] https://truegreengroup.com/tranport-news/ (accessed 10/11/2021)
[23] https://www.volvotrucks.com.au/en-au/trucks/trucks/volvo-fl/volvo-fl-electric.html (accessed 10/11/2021)
[24] https://hyundaitrucks.com.au/news?view=article&id=67:hydrogen-stacks-on-the-cards&catid=8 (accessed 10/11/2021)

Articulated trucks

Articulated trucks are the only class with no current uptake of electric vehicles. There are currently no advertised vehicles available in Australia that serve this segment. Some manufacturers are beginning to offer battery electric vehicles overseas in this segment, such as Volvo[25] and Tesla[26], however, these are not currently available in Australia.

Hydrogen vehicles are getting relatively more traction in this class. Several companies such as Hyunai[24], Nikola[27], and Hyzon[28] are developing vehicles in this class.

Australia's current laws allow for 2500 mm-wide trucks to operate unrestricted on Australian roads[24], although Austroads has supported increasing widths to 2550 mm [25]. This is narrower than both US (2600 mm) [26] and Europe (2550 – 2600 mm) [27], and is a barrier to uptake of international models in Australia.

Overall, the CRI is assessed at **2: Small-scale trial**. There is a lack of available vehicles and demonstrated use cases in Australia.

Successes	Gaps
• International vehicles beginning to be available	• Price premium • No Australian deployments • Barriers in standards • Availability of supporting infrastructure • Industry supply chain and skills

Non freight carrying trucks

Non freight carrying trucks includes specialised vehicles such as tow trucks, cherry pickers, ambulances, and fire engines. These vehicles are usually converted from more standard vehicle types (such as light commercial or rigid trucks). Due to the diversity in this class, it cannot be discussed at the top-down level with fidelity. However, there is existing interest in converting some non freight carrying trucks used in local council fleets (such as rubbish trucks) to zero emissions, and therefore potential to provide visible demonstrations.

Buses

Buses have the highest EV uptake of all larger vehicle classes. Several manufacturers are offering electric buses, including Australian manufacturers Bustech[29] and Custom Denning[30]. Public transport authorities are among the largest purchasers of buses. Many States and Territories have stated their plans to replace diesel buses with electric in the near term [28], [29]. Overseas electric buses are also becoming common. For example, Shenzhen has entirely replaced their fleet with electric buses [30].

Hydrogen buses are also being developed in Australia, for example TrueGreen and Foton have announced a partnership to develop hydrogen buses[31].

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[25] https://www.volvotrucks.com/en-en/trucks/trucks/volvo-fh/volvo-fh-electric.html (accessed 10/11/2021)
[26] https://www.tesla.com/semi (accessed 10/11/2021)
[27] https://nikolamotor.com/motor (accessed 10/11/2021)
[28] https://hyzonmotors.com/vehicle/ (accessed 10/11/2021)
[29] https://bustechgroup.com.au/products/#powertrain (accessed 11/11/2021)
[30] https://www.custombus.com.au/category/electric-bus/ (accessed 11/11/2021)
[31] https://www.busnews.com.au/industry-news/2101/foton-bus-australia-partners-with-truegreen (accessed 11/11/2021)

Overall, the CRI is assessed at **3: Commercial scale-up**. Electric buses are beginning to be rolled out in Australia in several locations and are forming part of plans. This is restricted to larger public transport organisations such as State governments.

Successes	Gaps
• BAU rollouts beginning to be undertaken • Australian manufacturing ramping up	• Price premium • Scaling to extend uptake to smaller operators • Availability of supporting infrastructure • Industry supply chain and skills

3.2.3 Usage and emissions by vehicle class

This section presents an analysis based on public statistical data [13], [31] to determine which classes of vehicles may be higher priorities for electrification. These surveys present information on vehicle usage by location and type of trip. The aim of this analysis is to direct effort towards vehicle classes or sub-classes that would be most impactful. This analysis uses Australian Bureau of Statistics (ABS) data on segment fuel usage and distance travelled to estimate the emissions impact of individual vehicles and classes.

The vehicle class emissions shown in Figure 7 are calculated according to the process set out in [32]. This figure illustrates that passenger vehicles are by far the highest-emitting class. This is simply due to the number of vehicles– 74% of vehicles in Australia are passenger vehicles. Passenger vehicles emit 42.9 Gt CO_2^e per year. Commercial transport (light, rigid, and articulated trucks) is also a large emitter, emitting 37.7Gt CO_2^e per year collectively. Most of these vehicles are diesel, which emits more particulates, nitrous oxides, and particulate matter than petrol engines [33]. Buses are a relatively low emitter in total, although they can be major contributors to public transport agency emissions. Motorcycles and non-freight carrying trucks are small emitters because of their very low numbers.

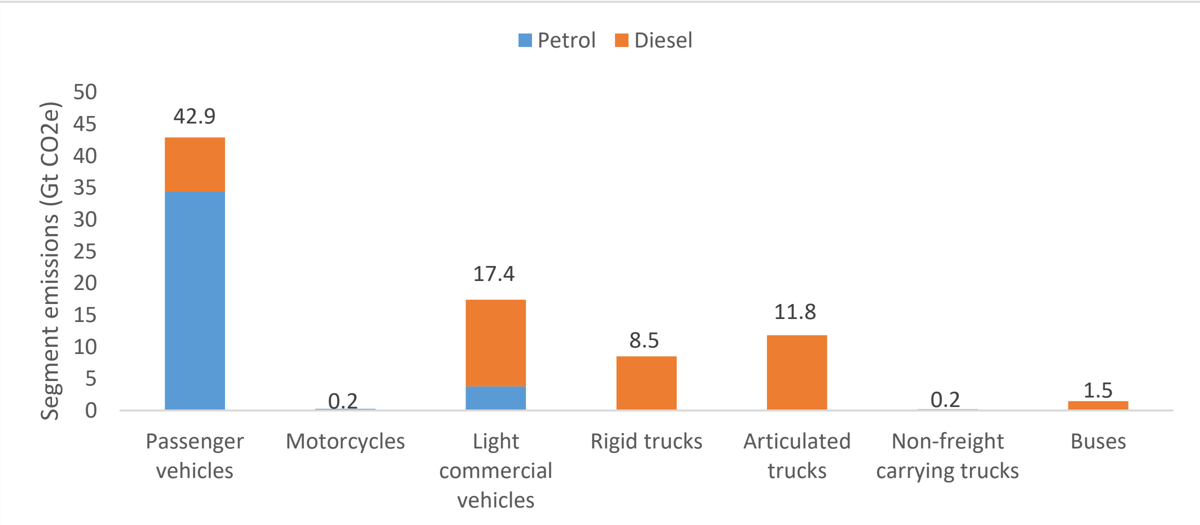


Figure 7: Total emissions by class

Figure 8 breaks emissions down into per vehicle/year and per kilometre for each class. Figure 9 shows the average daily trip length by class. This gives an indication of the impact of individual vehicles and travel kilometres. Articulated trucks are large vehicles and hence have high emissions.

Similarly, they drive long distances per day: more than three times the distance travelled by the next highest class (buses). Rigid trucks and buses are overall similar in emissions and round out the top three emitters on a per vehicle basis. Smaller vehicles emit less, particularly motorcycles which are small, light vehicles that on average only travel short distances.

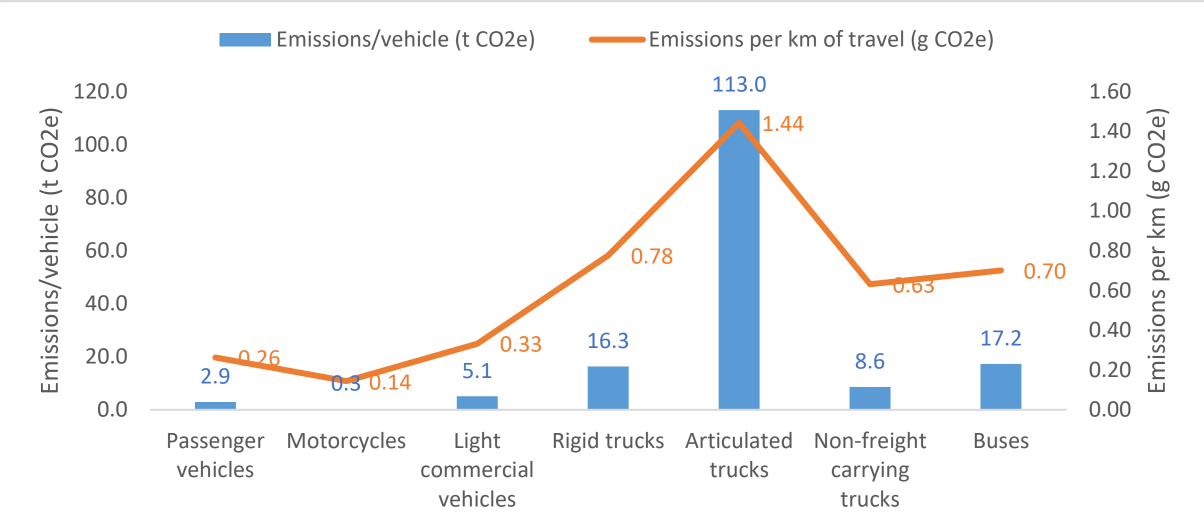


Figure 8: Emissions per vehicle and per km

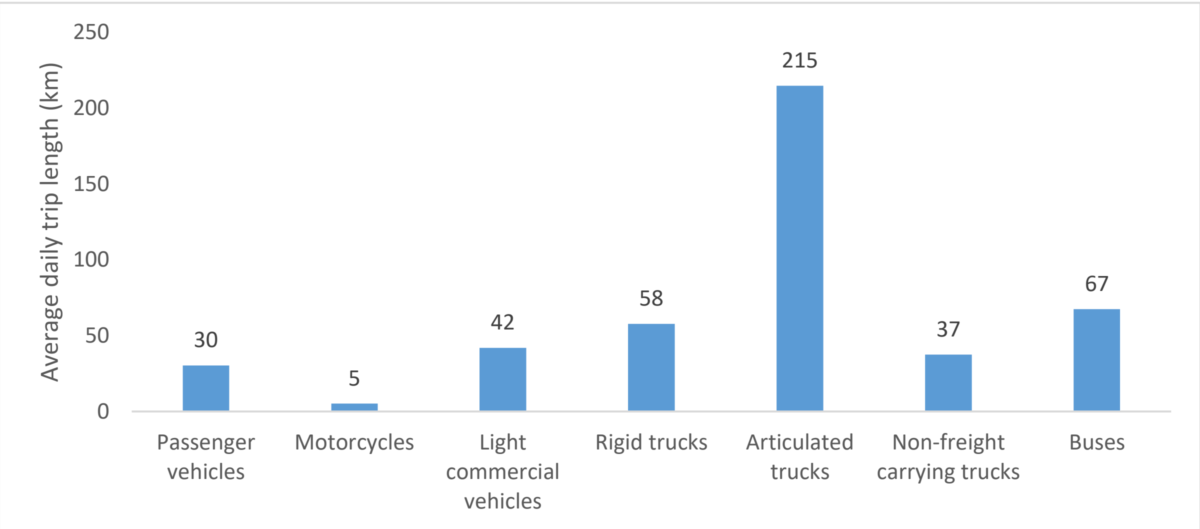


Figure 9: Average daily trip length by vehicle class

The ABS also gives statistics on the types of trips different vehicles make, broken down into several categories, as shown in Table 6. This provides the opportunity to consider how the length of a type of trip might affect the suitability of an electric vehicle. Current generation electric vehicles have shorter range than their ICE counterparts. On-route charging is possible but is still a barrier, especially for heavy vehicles (discussed further in chapter 3.3). For this analysis, trips are spilt into "short" or "long". Long trips are more likely to require either larger batteries or on-route charging. On route charging requires infrastructure to provide the charging and requires vehicles to stop to charge. Figure 10 shows trip length across vehicle classes. The obvious standout is articulated trucks. Most of their trips are long, as expected with their bulk transport role. Light commercials and rigid trucks also have somewhat longer trips than other classes.

Table 6: Trip types and classifications

Trip type	Classification
In the capital city	Short
Between the capital city & other parts of the State/Territory	Long
All outside the capital city - within 100 km of base	Short
All outside the capital city - beyond 100 km of base	Long
Between the capital and another capital city	Long
Other interstate - within 100 km of base	Short
Other interstate - beyond 100 km of base	Long

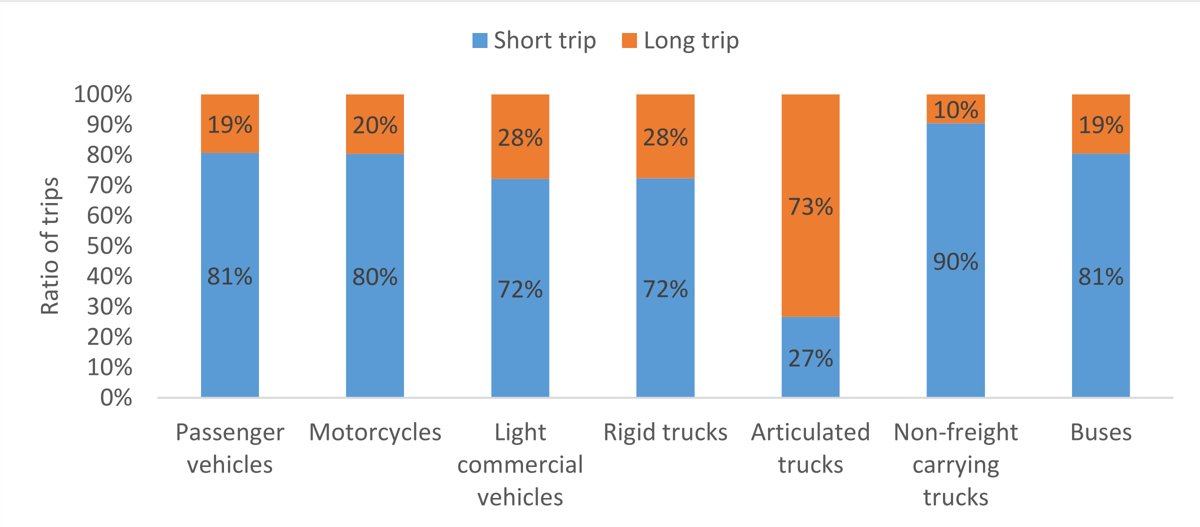


Figure 10: trip length by vehicle class

3.2.4 Findings and actions

This section has described vehicle classes and their current electrification status as well as their environmental impact. We now nominate the best actions for each class based on two factors:

- How developed is the class.
- How much impact is there in electrification.

Development is defined by CRI. A high CRI indicates a class with good EV availability and lower barriers.

Impact has diverse meanings. Some strategies have used "electric miles" or the impact of "like for like" replacement as a measure [34], [35]. These strategies focus on vehicle classes that have higher absolute emissions such as passenger vehicles. Other strategies take a "whole system" approach and consider impacts on congestion and liveability [7], [20], [21]. This report looks at both dimensions:

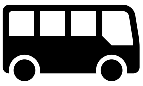
- **Class emissions** indicates the total emissions of the class. Higher emissions indicate higher impact.
- **Individual vehicle emissions** indicate the impact of each vehicle in the class. Higher emissions indicate higher impact.
- **Cross-sector benefits** indicates a classes potential to reduce emissions from other classes (such as through substitution).

Class and individual emissions are based on statistical data presented in this section. Cross-sector impact is based on an analysis of plans, such as those listed above.

The intent of this chapter is not to prioritise classes, rather it is to identify the actions that can be taken in each class to encourage electrification within. A summary of the findings from this analysis is shown in Table 7.

Table 7: CRI and emissions reduction priority for vehicle classes

Class	CRI	Factors			Action
		Class	Individual	Cross-sector	
Passenger vehicles	CRI 5 Vehicles are widely available, although still at a significant price premium.	High	Low	Low	Continue to encourage uptake. Foster a second hand market.
Motorcycles	CRI 4 Vehicles are becoming available, and price is competitive with internal combustion engine vehicles.	Low	Low	High	Encourage established manufacturers to increase model availability. Investigate initiatives to encourage substitution of other, higher emission, vehicle classes.
Light commercial vehicles	CRI 3 Relatively immature market. Vehicles have been announced and have small-scale adoption.	High	Medium	Low	Encourage vehicle market growth and trials that draw through commercialisation pathway.
Rigid trucks	CRI 2 There are vehicles beginning to be adopted but largely still in niche applications.	Medium	High	Low	Encourage vehicle development and test use cases.
Articulated trucks	CRI 1 Currently no vehicles in this class are available in Australia.	Medium	High	Low	Encourage vehicle development and test use cases.

Class	CRI	Factors			Action
		Class	Individual	Cross-sector	
 **Non-freight carrying trucks**	Unrated: vehicles of this class are modifications of vehicles from other classes.	Low	Mediumlas	Low	Investigate specific use cases in line with vehicle type availability. Engage with system integrators.
 **Buses**	CRI 4 Widespread overseas. Similarly, stated goals from public transport companies, make this class the most commercially ready of heavy vehicles.	Low	High	High	Encourage vehicle market growth and trials that draw through commercialisation pathway.

3.3 Charging landscape

EVs are a technology that sits at a nexus between the energy and transport systems [36]. They are primarily a transport device but are powered by electricity, and their charging requires integration into existing electricity infrastructure. Ensuring vehicles can charge easily is commonly cited as one of the most critical factors to enable electrification [34]–[37].

This section explores:

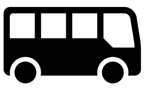
- The current state of vehicle charging across vehicle classes.
- The suitability of existing infrastructure, including charge needs, across vehicle classes.
- Cross-cutting themes.

In considering charging it is important to consider the expected needs of the vehicles. This is driven by battery capacity, use cases, and daily drive distances. Table 8 shows indicative specifications for range and battery capacity, together with ABS data on vehicle use.

Table 8 Approximate specifications of vehicles across classes

Class	Charging needs	Vehicle uses [31]	
 **Passenger vehicles**	**Approximate battery capacity**[32]**:** 30-100kWh (200-600km) **Average daily drive distance:** 30km	**Business use** **Personal use** **To and from work use**	19% 54% 27%

[32] https://rac.com.au/car-motoring/info/electric-cars-australia (accessed 11/11/2021)

Class	Charging needs	Vehicle uses [31]
 **Motorcycles**	**Approximate battery capacity**[33]**:** 1-20kWh (50-200km) **Average daily drive distance:** 5km	**Business use** 9% **Personal use** 59% **To and from work use** 32%
 **Light commercial vehicles**	**Approximate battery capacity**[34]**:** 40-180kWh (200-600km) **Average daily drive distance:** 42km	**Personal use** 24% **To and from work use** 15% **Commodity transport** 44% **Other work use** 17%
 **Rigid trucks**	**Approximate battery capacity**[35]**:** 100-700kWh (200-800km) **Average daily drive distance:** 42km	**Personal use** 1% **To and from work use** 2% **Commodity transport** 70% **Other work use** 27%
 **Articulated trucks**	**Approximate battery capacity**[36]**:** 400-1,000kWh (200-800km) **Average daily drive distance:** 215km	**Commodity transport** 72% **Other work use** 28%
 **Non-freight carrying trucks**	These vehicles will be like light commercial and rigid trucks	**Other work use** 100%
 **Buses**	**Approximate battery capacity**[37]**:** 200-600kWh (150-800km) **Average daily drive distance:** 67km	**Personal use** 3% **To and from work use** 1% **Route service** 37% **Dedicated school bus service** 17% **Charter service** 18% **Tour service** 4% **Other bus services** 21%

Charging needs are driven by use cases. For this report charging has been broken up into two groups: private and public. These are described in Table 9.

[33] https://www.fonzmoto.com/arthur/overview, https://www.harley-davidson.com/au/en/motorcycles/livewire.html (accessed 10/11/2021)
[34] https://rac.com.au/car-motoring/info/electric-cars-australia, https://www.drive.com.au/news/rivian-electric-ute-and-suv-arrive-in-australia/ (accessed 11/11/2021)
[35] https://www.electrive.com/2020/06/14/dpd-switzerland-gets-electric-truck-with-680-kwh-battery/, https://www.sea-electric.com/products/seadrive100/ (accessed 11/11/2021)
[36] https://en.byd.com/wp-content/uploads/2018/07/8tt_redesign6-23-18.pdf (accessed 11/11/2021)
[37] https://www.proterra.com/vehicles/proterra-powered-vehicles/bustech-transit-bus/, https://www.electrive.com/2018/03/05/daimler-releases-spec-electric-city-bus-citaro/ (accessed 11/11/2021)

Table 9 Types of EV charging

 **Private charging**	Charging that is available to one, or few users. For example: • Home charging for personal vehicles • Work charging for employees or fleets • Limited access charging such as taxis, bus route charging
 **Public charging**	Charging that is open-access. For example: • Destination charging at shopping centres or car parks • Fast charging on transit routes

3.3.1 Private charging

Most reports indicate that private charging is the most common charging type [38]–[40]. Private charging varies significantly depending on application, speed, cost, and effort, as shown in Figure 11.

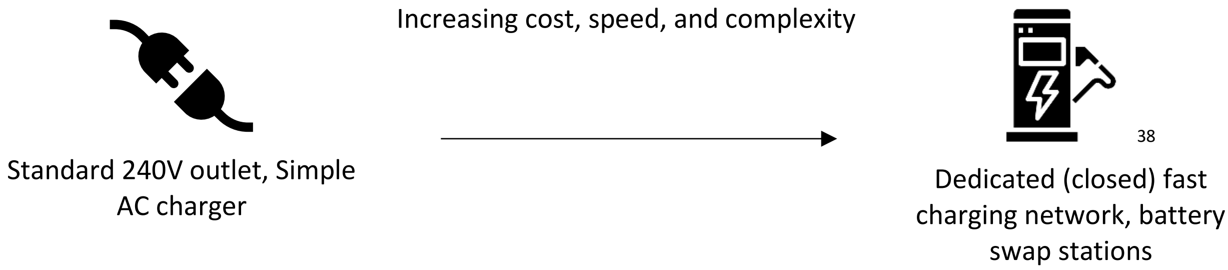


Figure 11 Spectrum of private charging

Private charging may be used for multiple reasons:

- **Cost:** Private charging is often cheaper, particularly if the location has access to low cost energy [36], [40], [41].
- **Sustainability:** Private charging can make use of locally-generated energy [36], [41].
- **Convenience:** Private charging may be more available or fit better with vehicle usage profiles (e.g. overnight) [38], [41].
- **Usage requirements:** Vehicles may either not travel to public chargers, require full charger availability, or require specialised charge equipment – particularly for heavy vehicles [42], [43].

There are several contexts in which vehicle owners may use private charging. These are summarised in Table 10.

[38] Icon courtesy of smalllikeart from www.flaticon.com

Table 10 Private charging locations and factors

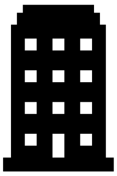
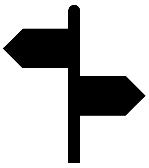
 **Home**	Home charging is where vehicles charge at home. Several factors impact home charging: • Energy needs such as grid connection requirements, grid services relationships, tariffs, and tie in with existing generation (such as PV) [44]–[47], • Physical installation constraints such as quality and safety of home wiring, maximum demand limits, distance to parking [48], [49], • Revenue and cost implications of charging work-provided vehicles at home [46], [50], • Home ownership or access to parking (e.g. apartments) [50], [51].
 **Workplace**	Workplace charging is where vehicles (either company owned or private) charge at a workplace. This includes fleet vehicles and employee vehicles. Fleets can include vehicles from across the spectrum of classes. These will each have unique charging requirements. There is significant diversity in charger types, relating to vehicle usage. The key issues are: • Energy needs such as grid connection requirements, grid services relationships, tariffs, and tie in with existing generation (such as PV) [47], [52]–[54], • Physical installation constraints such as wiring adequacy, maximum demand limits, distance to parking places, and access limitations [47], [54], [55], • Cost and recovery of costs from employee charging [56], • Building and parking access and ownership [47], [57].
 **Public area**	Private charging networks may exist in public areas for several reasons: • Vehicles on scheduled route services (such as buses) may need to charge on-route [30], [53], • Vehicles which have high usage factors (such as taxis) may not tolerate congestion at public chargers [58]–[60], • Vehicles which normally park on-street (such as ride share or apartment residents) [61], • Vehicles may have specialised charging needs such as pantographs, wireless charging, battery swap, or hydrogen, especially heavy vehicles [62]. There are several influential factors: • Energy needs including distribution network requirements and metering [47], [63], • Physical installation constraints such as locating and protecting assets [47], [63].

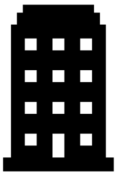
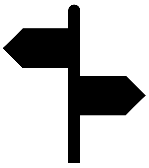
Table 10 shows there are several common issues, as well as unique ones for each segment. These relate to energy costs, and physical installation.

Charging site considerations can be complex [55]. The Rocky Mountain Institute found that installed costs for chargers were 3-5 times the hardware costs. Much of the additional cost could be attributed to “soft costs” such as communication between parties, gaining access to easements, and complex codes and permitting processes [47]. Leased buildings or installing chargers in shared spaces are particularly complex due to multiple stakeholders, responsibilities and split incentives. Similarly, there are no consistent standards between different energy stakeholders and councils around how chargers are to be installed in shared spaces. The Rocky Mountain Institute found that these soft costs are commonly a reason why a particular charging site may be abandoned [47].

Physical installation constraints may be eased over time by improved building codes. The National Construction Code 2022 update draft has included provision for electric vehicle charging for class 2-9 buildings, which includes apartments, commercial and institutional buildings [64]. These recommendations don't include detached and semi-detached residences based on the assumption that the barriers to installing private charging are lower for these buildings.

Overall CRI for private charging is shown in Table 11.

Table 11 CRI private charging

	Overall CRI	Successes	Gaps
 **Home**	5	• Standard chargers are available off-the-shelf • Custom energy pricing products beginning to become available	• Lack of standard processes, tools, and products to enable work vehicles to charge at home • Rented homes, apartments, and homes with no driveway have barriers
 **Workplace**	4	• Light vehicle charging is available off the shelf • Established organisations offering services to organisations	• Heavy vehicle depot charging poorly understood • Revenue/billing models for employee charging not well defined • Retrofit is expensive
 **Public area**	2	• Overseas experience proves it can be done	• Few examples

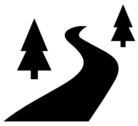
3.3.2 Public charging

Public charging accounts for a smaller total percentage of charging. However, it is critical for widespread uptake of EVs [34]–[36], [65]. Vehicles will need to charge on-route during longer trips. Similarly, some EV owners will not have access to home charging. A suitable charge network has:

- Chargers at appropriate locations.
- Chargers of sufficient capacity [65], [66].

There are two common classifications of public chargers, shown in Table 12. This report considers on-route and destination charging separately.

Table 12 Public charger types [66]

 **On-route**	**On-route** chargers provide quick top-ups of energy during a trip. They are analogous to petrol stations.
 **Destination**	**Destination** chargers enable vehicles to charge while vehicles are parked at locations for longer times. For example, public car parks or shopping centres.

On route charging

On-route chargers aim to minimise charge time so that vehicles can continue their journeys. These chargers generally have a power capacity of 50kW or greater [34], [35], [66]. Today, most public on-route chargers are between 50 kW and 350 kW [67]. Figure 12 shows the frequency of the power ratings of current fast chargers in Australia. Table 13 illustrates how well common current fast chargers sizes suit vehicle classes based on theoretical charge time.

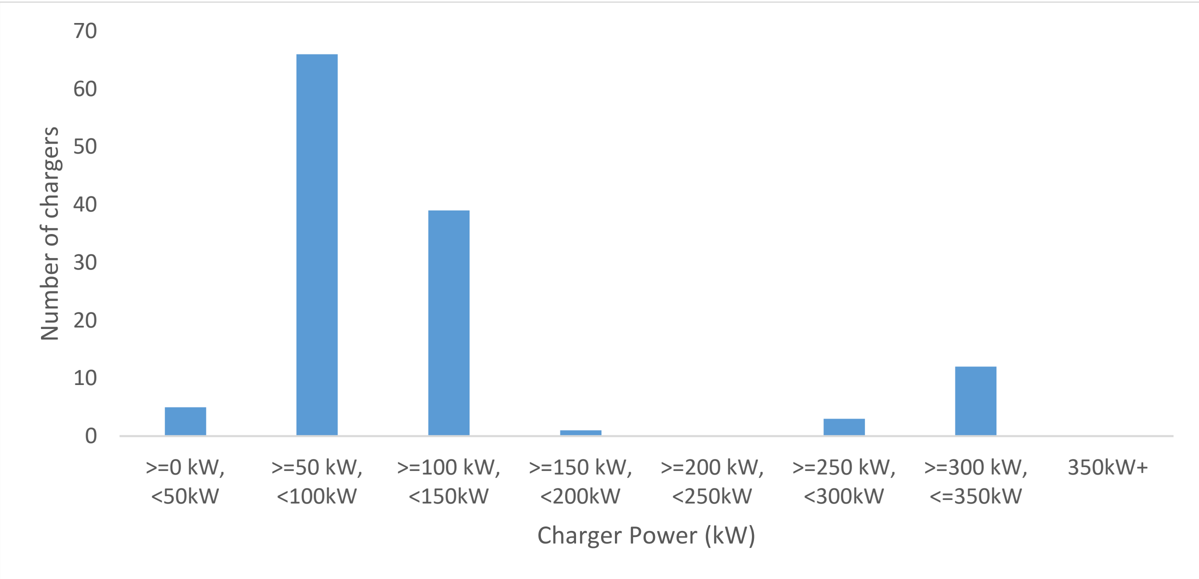


Figure 12 Histogram of public fast charger power capacities [68] as of 16/9/2021

Table 13 Illustrative[39] charge times for common on-route public charger sizes

Size	Passenger vehicles	Motorcycles	[2] Light commercial vehicles	Rigid trucks	[2] Articulated trucks	Buses
50kW	1-2h	<1h	2-4h	4h+	4h+	4h+
100kW	<1h	<1h	1-2h	4h+	4h+	4h+
350kW	<1h	<1h	<1h	1-2h	2-4h	1-2h

Smaller chargers (in the 50-100kW range) are only suitable for light vehicles. Trucks and buses may require very long charge times at these chargers – particularly models with large batteries. Developers of these vehicle types expect to construct dedicated charging networks to support these larger vehicles. For example, a report by the European Automobile Manufacturers Association indicated that 10,000-15,000 (higher-power) public and destination charging points for heavy vehicles would be required in Europe no later than 2025 [69].

There is an increasing number of on-route chargers in Australia. The EV Council indicates there are around 470 public fast chargers in Australia [70]. Figure 13 shows the density of fast chargers across Australia by population and area. Chargers by population gives an indication of congestion at charger sites, and chargers by area gives an indication of coverage. Tasmania, ACT, NSW, and Victoria have the largest number of chargers by area. This list contains both the smallest and the most populous states. Larger and less populous states such as NT, SA, and WA are more challenging to provide charge infrastructure in and thus have significantly less coverage than the smaller or more populous states.

Figure 14 shows the distribution of fast (>=50kW) and ultra-fast (>=150kW) chargers on a map. The uneven density of fast chargers is especially apparent on this map. Currently the only interstate routes with complete coverage are between Victoria, ACT, NSW, and QLD. Tasmania has the most complete coverage of fast chargers, due to its smaller size and government grant programs [71].

[39] Charge time is based on battery capacity and charger speed. In real-world environments there are many other factors that influence charging time such as the car's capabilities, temperature, and state of charge. Real charge times will be longer than stated here.

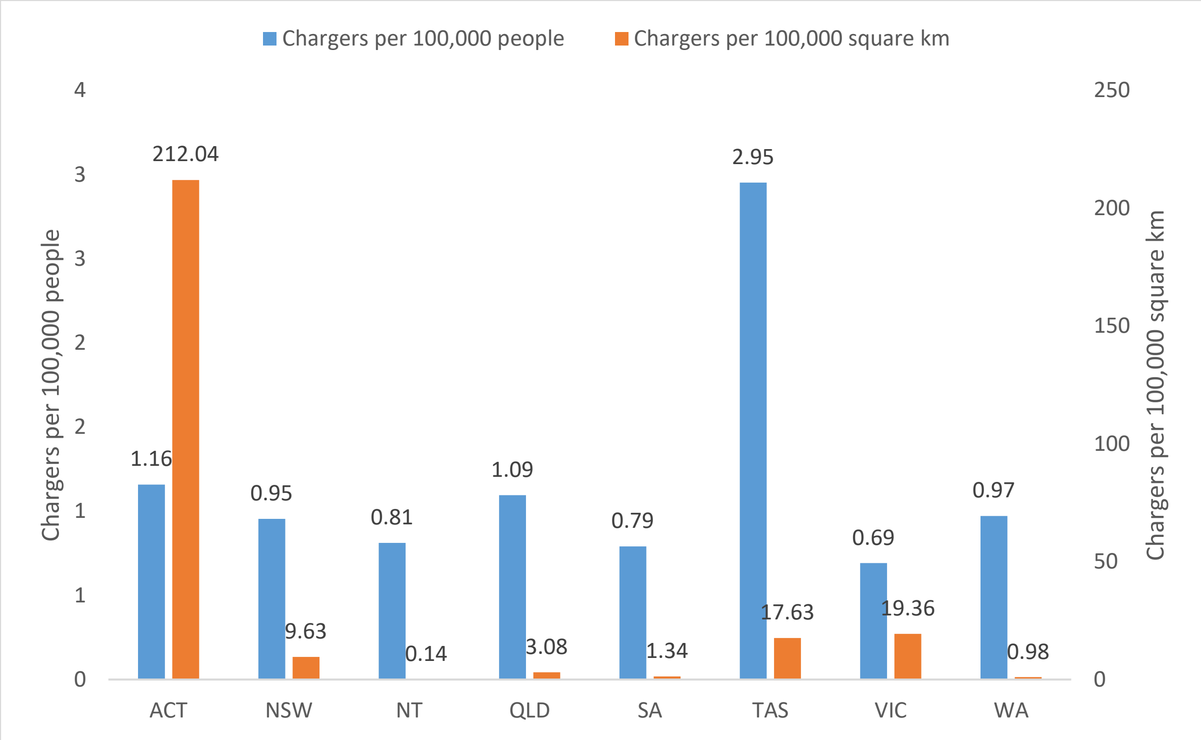
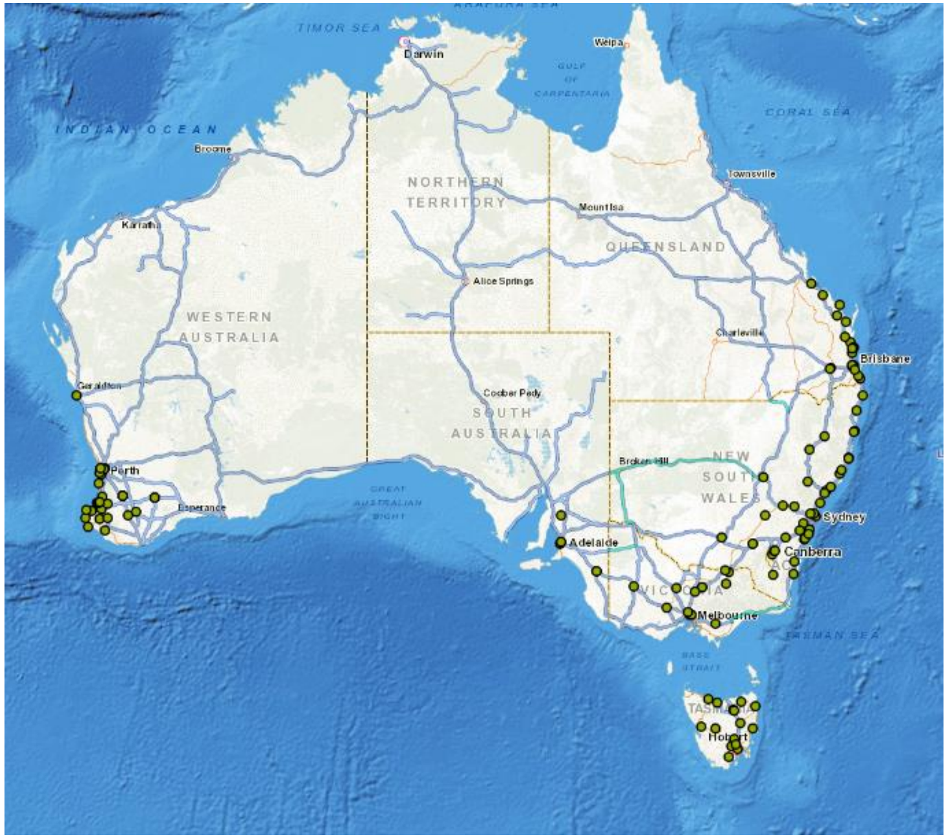


Figure 13 Fast charger density by area and population [70], [72]



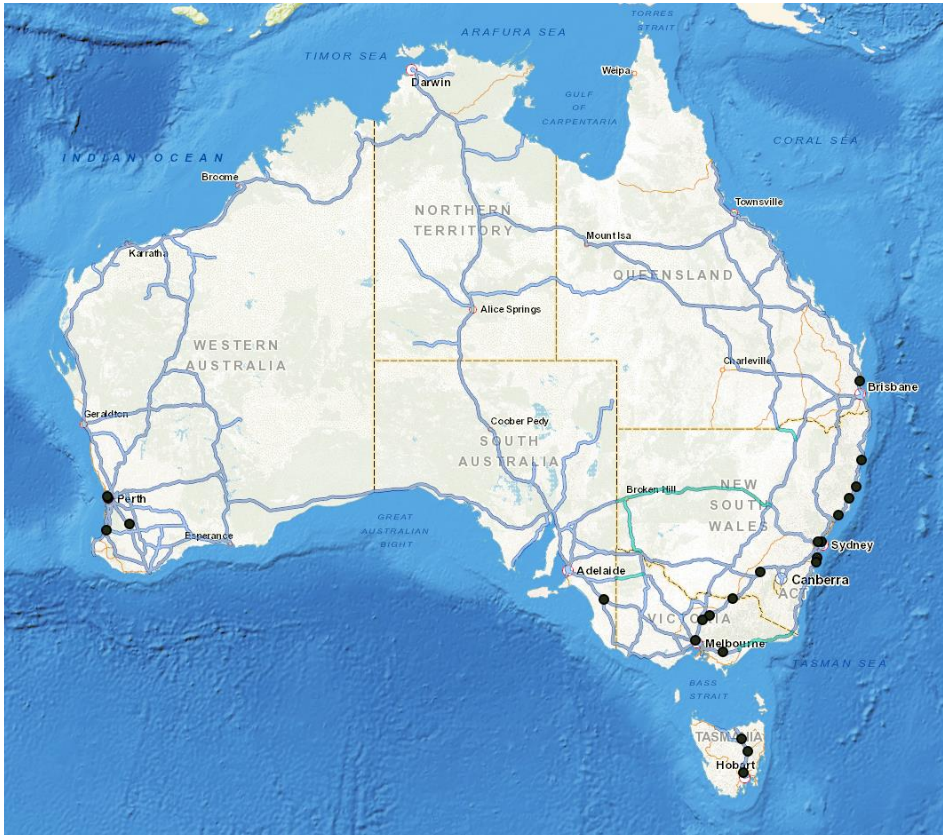
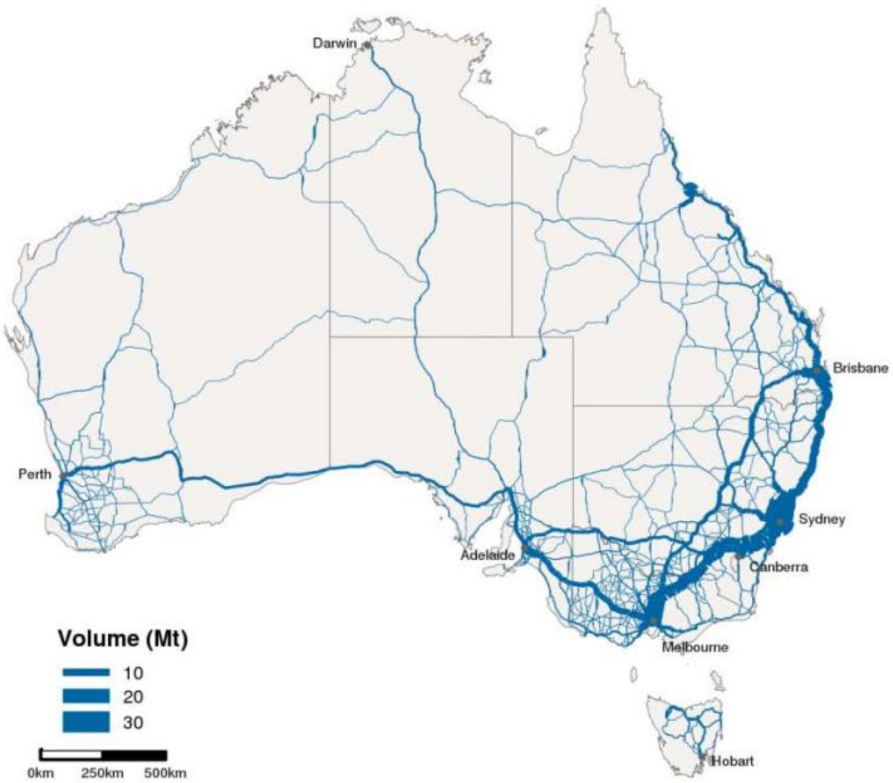


Figure 14 Major freight routes and current Australian fast chargers as of 22/09/2021: 50kW+ on left, 150kW+ on right [68], [73]

As described above, the current EV charge network is unlikely to be suitable for heavy vehicles. For long distance transport it is more unclear whether battery electric or hydrogen fuel will become more common [74]. Either way the fuel supply network will require rapid development as the transport industry decarbonises. Freight commonly travels between hubs along specific routes. These are shown in Figure 15. Clearly the most common freight routes are along Australia’s eastern seaboard: Melbourne, Brisbane, and Sydney. The most common freight routes are the Hume Highway (Sydney-Melbourne), Pacific Highway (Sydney-Brisbane), and Newell Highway (Melbourne-Brisbane). While studies have been completed (such as by BITRE [74]) on establishing low emissions refuelling (recharging) networks along these routes, there are no active projects to deliver them.



Source: ABS (2002) and BITRE estimates.

Figure 15 Road freight movements in Australia [75]

Destination charging

Destination charging enables vehicles to charge where they are parked away from home. This for example may be at shopping centres, “park and ride” services, tourist attractions [76] or warehouses (for heavy vehicles) [77]. Commonly these applications use lower power, cheaper chargers than on-route chargers [76]. Although experience with REVS has still shown that installation of chargers in commercial properties can be complex [55]

In interviews as part of the Realising Electric Vehicle-to-grid Services (REVS) project, several participants suggested destination charging (particularly workplace and “park and ride” services) would be promising resources for grid services. This was because of the high density of vehicles, and because vehicles will cluster close to load centres (e.g. in city centres during the day). This is discussed further in 0.

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Overall CRI for public charging is shown in Table 14.

Table 14 CRI public charging

	Overall CRI	Successes	Gaps
On-route – Light vehicles	4	• Significant rollout of chargers already on some major routes	• Still significant gaps in coverage, particularly in regional areas
On-route – Heavy vehicles	1		• No current heavy vehicle focused EV charging infrastructure
Destination charging	5	• Chargers are relatively cheap and available	• Complexity of installation in commercial properties

3.3.3 Findings and actions

This chapter has summarised the current state of EV charging. A summary of charging related segments and their findings is shown in Table 15. These recommendations do not prioritise between charging types as all types are important: one is not a replacement for the other.

Table 15 Charger segment analysis CRI and importance

Segment	CRI	Recommendation
Home	**CRI:** 5 Home charging is readily available for people with a location to install the chargers.	Continue initiatives to enable home charging. Notable gaps exist in apartments, rented properties, properties with only on-street parking, and charging work-provided vehicles at home.
Workplace	**CRI:** 4 Chargers are technically like home chargers for light vehicles, but heavy vehicle charging is still a barrier. Installation and billing can be complex.	Future initiatives should investigate: • Depot charging (particularly for heavy vehicles). • Workplace charging of private vehicles.
Public area, private network	**CRI:** 2 There are few private charging networks in public areas today.	Work should focus on working with local planning bodies and DNSPs to build rules and regulations to enable.
On-route (light vehicles)	**CRI:** 4 There are an increasing number of these chargers installed across Australia.	Work should focus on filling significant gaps in coverage in regional areas. Similarly, density of chargers in urban areas will need to improve.

Segment	CRI	Recommendation
On-route (heavy vehicles)	**CRI:** 1 There is currently no heavy vehicle charge (or hydrogen) infrastructure.	This gap must be filled before bulk transport emissions can be tackled therefore should be considered a priority.
Destination	**CRI:** 5 This type of charging uses similar technology to home or workplace charging.	Continue initiatives to enable destination charging.

3.4 Grid services

EVs are a mix of risks and opportunities for the electricity grid. They are a risk due to peak demand and congestion impacts of co-incident charging. But with the right settings in place, the flexibility of this demand and the potential of utilising the electricity stored in EVs could generate significant benefits[36]. This enables them to not only avoid harm but also to generate wider value for the energy sector.

The transportation grid services landscape has several factors that influence it. They are discussed here in four dimensions:

- What services could a vehicle provide?
- What underlying technology could provide it?
- What is the potential of different classes of vehicles?
- What is the potential of different charging types (such as destination, fast, or home charging)?

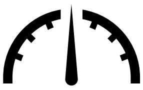
Key Takeaways from this section

- **Local peak shaving** and **contingency Frequency Control Ancillary Service (FCAS)** services are most developed in Australia currently. Other services such as **reliability** are promising.
- **Charger-based** service delivery is actively being trialled; **vehicle-based** service delivery is an opportunity to be further explored. **V2G** is early in the development curve.
- **Home, Workplace,** and **Destination** charging are promising sources for grid services. Home and workplace are actively being trialled, however destination charging is an unexplored opportunity.

3.4.1 Types of services

At its core, grid services involve shifting demand from times where there is insufficient capacity to times where there is excess. This can be over long or short time periods and can be automated or manual response. A listing of grid service types is in Table 16.

Table 16 Types of grid services [36], [78]

Type	Description	Potential Services
 **Energy and capacity**	These are traditionally longer-term services that optimise generation and demand. For example, shifting consumption out of high-cost times or demand to low-cost times.	• Local peak shaving • Intra-day balancing
 **Reserves**	Reserves are capacity that can respond quickly to events. These can be continuous (e.g. regulation FCAS) or event-based (e.g. contingency FCAS) services.	• Regulation FCAS • Contingency FCAS • Virtual synchronous machine
 **Other services**	These are system services that don't fall under energy and capacity or reserves. They include services such as reactive power, black start, or reliability/resilience.	• Reliability • Reactive Power

Grid services have different patterns that define when and where they can provide value. For example, demand shifting services are most valuable when they are located near areas of constraint [36]. This needs to be overlaid with the availability, capacity, and capability of the vehicles which are providing services.

Similarly different services have different technical requirements. Energy and capacity are the simplest services to implement and can be as simple as timing demand to occur during typically unconstrained periods, for example as is done with time of use tariffs. Other services require more active control or additional hardware capabilities.

Grid services are built on a framework of technical, economic, and commercial factors. A summary is shown in Table 17, including an estimated CRI for each grid service when provided by EVs.

Table 17 Services and current state [36]

Service	Who benefits?	How value is realised	CRI: EVs
Local peak shaving	Distribution, transmission networks	Through regulatory processes (RIT-D, RIT-T) or passed on to customers (operating envelopes, dynamic pricing)	**4:** Has been demonstrated overseas and is being demonstrated in Australia.
Intra-day balancing	Energy retailers, generators, distribution networks	Through better realised market prices for generators, lower energy costs for energy retailers, and better capacity management for distribution networks	**4:** Has been demonstrated overseas and is being demonstrated in Australia.
Regulation FCAS	Energy retailers, generators	FCAS market revenues	**3:** Has been demonstrated widely overseas.

Service	Who benefits?	How value is realised	CRI: EVs
Contingency FCAS	Energy retailers, generators	FCAS market revenues	**4:** Has been demonstrated widely overseas and is being demonstrated in Australia.
Virtual synchronous machine	Transmission networks, AEMO	Procured by transmission networks in response to AEMO identifying shortfall	**1:** Emerging service that is yet to be demonstrated on EVs.
Reliability	Distribution networks	Through regulatory processes (RIT-D, RIT-T)	**2:** Yet to be demonstrated, but some chargers are capable at a hardware level [79]. Similarly, vehicles such as the Hyundai Ioniq 5 offer V2L capability which can provide reliability services to individual customers [80].
Reactive Power	Distribution networks, transmission networks	Through regulatory processes (RIT-D, RIT-T)	**1:** There is not yet a clear monetisation path for this service.

3.4.2 Technology

The services described in 3.4.1 all have different implications for the technology of EVs and their chargers. In this report capabilities are described in three dimensions: Control, hardware, and speed.

Control refers to how the charger is controlled. This can be manually, through timers, or via an API (remote control) [36]. Manual charging is the simplest. Users can enact this control by choosing when their vehicles are connected. Similarly, many vehicles and chargers are equipped with timers that enable charging to be scheduled to lower cost times of day. API enables remote control of devices. Currently there is no single standard for API control of EV chargers [81]. Open Charge Point Protocol (OCPP) is a common standard that defines control between the charger and control system [82], while other standards cover other parts of the charger control stack (such as between charger control services and the energy system). Currently communication direct to vehicles is achieved by manufacturer-specific protocols. Interoperability will be important to enabling grid services from EVs [83].

Hardware is the physical topology of the charger. Most chargers have a simple internal topology that only allows vehicles to consume active power (charge). Bidirectional chargers can generate or consume active power and unlock more services, or the ability to do existing services better. Some bidirectional chargers can provide reactive power; however, this is not true of all bidirectional chargers [84], [85].

Services also have different speed requirements. Some of these can be implemented with longer lead times (for example using time-of-use tariffs for network capacity management). Some (such as virtual inertia) require millisecond control [36], [78], [86]. This has implications for the charger control method. High speed is more likely to require specialised local metering and control [36].

A summary of services and their technology requirements is shown in Table 18.

Table 18 Technical capabilities and services (adapted from [78])

Service	Minimum charger technology			Description
	Control	Hardware	Speed	
Local peak shaving	Timer	Single Direction	Day	Energy pricing that incentivises consumption at unconstrained times.
Intra-day balancing	API	Single Direction	Minute	Controlling charging in realitime to balance with variable generation or market price.
Regulation FCAS	API	Single Direction	Minute	High-speed response to power control setpoints.
Contingency FCAS	API	Single Direction	Second	Fast local response to locally-measured frequency.
Virtual Synchronous Machine	API	Bidirectional	Millisecond	Millisecond response to locally-measured frequency.
Reliability	Manual	4 Quadrant	Second	Operation when connected to small/islanded power system.
Reactive Power	API	4 Quadrant	Minute	Reactive power provided on request or to locally-measured parameters (e.g. voltage).

The above capabilities can be implemented either as part of a charging system or through hardware in the vehicle. Currently charger-based control has seen more uptake in Australia (discussed further in section 4.2). Internationally, car-based control has also seen usage.

Most vehicles do not yet support V2G – either at a hardware or manufacturer support level [36]. Nissan Leaf is currently the only vehicle with explicit hardware and manufacturer warranty support for V2G and is thus the vehicle used in all V2G trials in Australian currently.

For the CRI assessment, the capabilities in Table 18 are simplified to three levels: V0G (manual control), V1G (managed or smart charging), and V2G. Each of these has a different CRI depending on whether the control is implemented as part of a charger or the car. This is summarised in Table 19.

Table 19 Levels of charge control

Level	Control	Hardware	Speed	CRI: Charger	CRI: Car
V0G	Timer	Single Directional	Day	**6**: Most dedicated chargers have a timer functionality.	**6:** Most cars have timer functionality built in.
V1G	API	Single Directional	Second	**4:** “Off the shelf” hardware is being used in several trials across Australia.	**3:** Small-scale trials using existing capability in some vehicle makes.
V2G	API	4 Quadrant	Second	**2**: Small scale trials such as REVS are proving technology.	**1:** Has been trialled overseas but yet to see application in Australia.

3.4.3 Vehicles

For EVs to provide grid services they must be plugged in when called upon and have sufficient battery capacity.

These variables are difficult to generalise across fleets, however there is publicly available data on availability and capacity of privately owned EVs from UK-based projects [87] and the REVS V2G trial in Canberra will provide analysis of vehicles in the ACT government fleet. Many gaps remain, however. Future projects should focus on generating additional public data sources to fill these gaps.

3.4.4 Locations

The location of chargers is another key variable in providing grid services. Some are more suitable for provision of grid services than others. The value for grid services is largely a question of flexibility, which is influenced by location as well as the charger speed. If a vehicle is expected to only need a small percentage of its plug-in time to charge, then it is flexible and has good grid services potential. Vehicles using slower chargers and vehicles with higher daily travel requirements will spend most of their plug-in time charging, making them less likely to be good grid services resources due to low flexibility.

There have been some efforts to quantify flexibility for different charge contexts both in Australia and internationally. For example, Develder et al defined flexibility for home, (near) workplace, and destination charging for passenger vehicles, finding more scope at home and workplaces [88]. BMW investigated flexibility at multiple locations as part of their “ChargeForward” project. They found that drivers had significant opportunity to increase the number of times and locations they charged at, enhancing flexibility further. In addition to dwell time, flexibility relies on incentives to increase plug in rates at critical times and places [89].

To date, overnight (home, workplace) charging is most studied internationally and in Australia. This is not unexpected: vehicles do most of their charging and have the longest dwell time at these locations. Daytime charging (such as park-and-ride destination charging) was described as a promising grid services resource in discussions with several stakeholders as part of the REVS project. Other charge types such as fast charging may be less likely to be suitable because vehicles have only a short dwell time – typically around 25 minutes [90] - and require large amounts of energy in this time.

Table 20 shows the current understanding of grid services from the charge locations described in 3.3.

Table 20 Suitability of different charging types for grid services

Class	Assessment
Home	Vehicles have a long dwell time at home. There is significant optimisation potential during this time, as has been shown in several Australian and international projects (see section 4 and [36], [91]).
Workplace	Workplace charging could serve employees or fleet vehicles. Employee charging coincides with high building demand and high PV generation periods. Fleet vehicle charging is more likely to be overnight.
Public area, private network	Public area, private network chargers have a similar function and purpose to on-route charging and thus must focus on maximising energy transfer in a short time. Others in this group, such as apartments or ride-share services may have more potential. More work is required to quantify the scope in this area.
On-route	Chargers in this group must focus on maximising energy transfer in a short time. It is unlikely chargers in this group will prioritise grid services.
Destination	Destination chargers are potential grid services providers. Parking garages have many vehicles in a small area and can have critical mass of vehicles to meet market thresholds.

3.4.5 Summary: grid services

Grid services is a diverse area. In considering where gaps and opportunity lies it is important to consider technology, vehicles, and charge contexts as well as the services themselves.

Some service types are more developed than others. Local peak shaving, intra-day balancing, and contingency FCAS is being actively trialled in Australia. Other services such as regulation FCAS are being trialled overseas. Backup services are still conceptual, however V2L capability is becoming available.

Charger control and hardware are critical enablers of grid services. This can be accomplished through charger- or vehicle-based control mechanisms. Currently charger-based control is much more developed. More projects are based on this sort of control and there is more standardisation in control methods. Vehicle-based is increasingly becoming available on vehicles. V2G is still early in its development – especially when based on-vehicle.

Current projects have mostly focussed on passenger vehicles in Australia. There is not enough public data available to assess the potential of vehicles across classes.

Most current grid services projects are based on home or workplace charging. These charging contexts have longer dwell times so are highly suitable for service provision. Other charge locations are less studied. Destination charging was suggested in our consultation as having good grid services potential, but is not well studied.

3.5 Grid enablers

While there is much potential for EVs to provide grid services (as discussed in 0), there are many studies that also indicate that EVs may also cause constraints in the network [44], [92], [93]. Likewise, rigid network constraints may impede the connection of new charging infrastructure. This chapter assesses this through two dimensions:

- The potential for different vehicle and charger classes to cause or be impeded by network constraint.
- The enablers currently being proposed by industry, and their CRI.

Currently in Australia, as identified in the grid services chapter 0, there is a lack of data on vehicle usage. This gap is particularly large for non-passenger vehicles as there is also little international data to call on.

Key Takeaways from this section

- EV charging is well understood to impact the grid. Most work to date has focussed on **home** and **workplace** charging. The ability of **fast charging** to manage demand is not well explored
- Grid impact of **heavy vehicles** is poorly understood
- **Operating envelopes** and **time-of-use** price signals are being trialled and entering mainstream. **Dynamic prices** are an unexplored opportunity.

3.5.1 EV impact on the grid

The key detrimental impact EVs may have on the grid is on congestion, as demonstrated by several studies, projects, and trials [44], [92]–[94]. EVs charged simultaneously or during peak periods may cause constraints that require investment to relieve. The risk of constraint can be indicated by the charging demand relative to local network capacity and the probability charging will occur at times the network is already constrained. Larger chargers connected to relatively weak networks are also more likely to cause constraints. During interviews to test findings in this report participants described challenges this variability created in connecting chargers to distribution networks.

In line with section 3.3, the following will consider grid enablers for fast, home and workplace/fleet charging.

Fast charging

Fast chargers are commonly expected to have little flexibility available for demand management, but a large impact on distribution networks [95], [96]. Some studies have proposed charge management that prioritises fast charger needs. For example, Khalkhali et al proposed managing fast charger demand using residential load flexibility [95] while Domínguez-Navarro et al suggested use of local storage and renewable generation [96]. As discussed in section 4.2, current fast charger rollouts in Australia have not explicitly focused on grid integration enables, although one, Chargefox's Goulburn site, has implemented a battery coupled with a local dynamic operating envelope [97].

Home charging

Home charging has been the target of most VGI work so far. This is with reason: Many studies have shown that large, uncontrolled loads like EVs can have significant impacts on distribution networks [44], [92]–[94]. Potentially as EV batteries get larger these impacts will increase. Therefore, work on enabling the grid to accommodate home charging should continue, with increasing focus on operationalising and commercialising enabling technologies.

Workplace charging

Workplace charging spans both fleet and employee use cases. Potentially sites can have large numbers of vehicles in a small place, such as depots and warehouses. While not a primary focus of the project, REVS is investigating operating-envelope based congestion management in fleets. Similarly, Origin Energy's smart charging project is considering local congestion management for fleet as well as private EVs [98]. Similarly larger overseas trials such as Optimise Prime[52] and Bus2Grid [99] can provide insight that is relevant to Australia. Heavy vehicle electrification is at a much earlier stage, and there is limited information available, but is potentially an important area for enabling charging as well as providing grid services.

3.5.2 Enablers

Much like grid services, mitigating EV impact on the grid will require technical, commercial, and operational solutions.

At a technical level, solutions are similar to those described in section 0 in terms of shifting charge demand outside of periods of constraint. In addition, technologies such as operating envelopes can help accommodate high local demands when overall network capacity allows. Grid enablers though are likely to be much more widespread than grid services. As described in projects and studies that have focused on distribution network impacts, without VGI measures EVs are likely to cause a wave of network investment, much of which is avoidable by application of enabling technology [44], [92]–[94].

From a technology standpoint the technology required is like that required for grid services. However, because participation in grid impact managements schemes is widely expected to be much more ubiquitous, it's more important to standardise.

There are several projects underway that can provide insight to how grid impact could be managed. These largely fall under two categories:

- Existing Photovoltaic (PV) integration technologies such as operating envelopes can be repurposed for EVs (as currently being trialled in REVS [100] and EV-Grid [101]).
- Price signals provided to customers or energy retailers encourage appropriate charging behaviour (as trialled by Austin Energy [102] and Octopus Energy [103]).

Operating envelopes for PV are currently being commercialised in Australia. Leading networks, such as South Australian Power Networks, are beginning to offer these as business-as-usual products [104]. Some trials, such as REVS and EV-Grid are implementing operating envelopes for EVs in demonstration. Notably there are gaps in public sharing of learnings for heavy vehicles and on-route charging.

Various price signals are available today as energy tariffs, such as Powershop's EV specific time-of-use energy tariff [105]. Time-of-use pricing can be managed simply on EVs today using timers. These tariffs are however based on existing network tariffs. No distribution networks currently offer EV-specific network tariffs. As EV uptake increases it is likely that these static signals will need to evolve to more dynamic signals in order to avoid creating new peaks.

Table 21 shows the CRI for grid management mechanisms described in this section

Table 21 CRI for grid management

Mechanism	CRI
Operating envelopes	**4:** Beginning to be deployed BAU for PV, with initial application to EVs underway in trial.
Static price signals	**5:** Existing EV-specific retail products are available, although based on non EV-specific network tariffs.
Dynamic price signals	**2:** Has been done overseas but not currently available or being tested in Australia.

4 Bottom-up analysis

This section examines the development in EV-grid integration through the lens of the various recent trials and projects around Australia. These include ARENA projects, other relevant projects funded through the Future Fuels Fund, and State and Territory-led projects.

The projects are discussed in three groups: grid-focused projects, which are primarily concerned with the optimisation of the grid via new technologies; charging-focused projects, which expand charging infrastructure; and vehicle-focused projects working on introducing new vehicle-related technologies (Table 22). There are also projects that involve consumer research or desktop study[40], which are considered where relevant.

Table 22: Project groupings.

Grid-focused	Charging-focused	Vehicle-focused
REVS [100] Origin EV Smart Charging [106] AGL EV Orchestration [107] Jemena EV Grid [101] SmartCharge Queensland [108]	Chargefox (2 projects) [109], [110] Evie Networks (2 projects) [111], [112] Electric Highway Tasmania [113] Ampol Fast Charging [114] ENGIE Fast Charging [115] Jolt (ad revenue, AusGrid) [116]	Energy Freedom Solar EV [117] ACE-EV [118] State and Territory Bus Trials [119]–[121]

4.1 People

Key Takeaways from this section

- There is strong representation of **networks**, **technology developers**, and **energy retailers** in current projects. **Community** and **end-user** groups are poorly represented
- Although there is a strong presence of networks in projects in general, **fast charging** projects generally lack these partners
- Projects so far have mostly focussed on **passenger vehicles** that **charge at home** and are not part of a fleet, although there is some developing focus on fleet vehicles. **Other vehicle classes** (such as trucks and buses) or use cases (such as taxis) are gaps.
- Projects so far have included participation only from vehicle owners with less complex charger installation. There are gaps in projects that aim to resolve barriers that make charger installation complex, such as **apartments, fleets**, and people who **don’t currently own an EV**.
- Fast charger projects do not typically invite participation from their **eventual end users** as part of the project.

4.1.1 Partners (stakeholders)

The partners to a project or trial set the terms. They define their own vision for the future and express it through the project, and likewise decide which visions are excluded [122]. For example,

[40] Other projects include Charge Together (https://fleets.chargetogether.org/) and C4NET (https://c4net.com.au/).

many trials envisage the seamless integration of EVs into people's lives [123], whereas others' visions for the future might be reduced reliance on automobility [124]. Trials therefore look very different depending on who is party to it, as this section will demonstrate.

Projects also conceive of how system change is produced; for example, a more efficient distributed grid is achieved through behaviour change in end-users, or EV adoption is accelerated by building more infrastructure and lowering barriers. Project partners also decide who can participate in the trial and who can't. It is therefore important to consider which types of organisations or groups are represented, and which are not. Partners and project makeup influences possibilities for the future and trajectories for technology development.

Figure 16 shows the types of partners projects could incorporate, based on existing research on VGI [125] and others identified as part of this report. This is not necessarily an exhaustive list. Figure 16 also shows how many current projects include these partners. Unsurprisingly, grid-focused projects always include networks as partners, as well as the developers and installers of hardware and software for grid integration. Retailers are often partners, but only REVS includes the vehicle owner (ACT government) as a partner.

Charging-focused projects nearly always involve a charging network and often a property partner such as a council or petrol stations. Only Electric Highway Tasmania has the users of the charging infrastructure as partners. Similarly, only Jolt includes Ausgrid, an electricity network, as partner despite the potentially high local network impacts of fast charging and potential for innovative solutions like dynamic operating envelopes (discussed in 3.5). However, it should be noted that many projects (such as Jolt) bring on network, retailer and other partners as they progress.

Passenger vehicle-focused projects include a more diverse group of partners. Announced projects include networks, technology developers, and vehicle manufacturers. As of the time of writing of this report electric bus projects are yet to be fully announced.

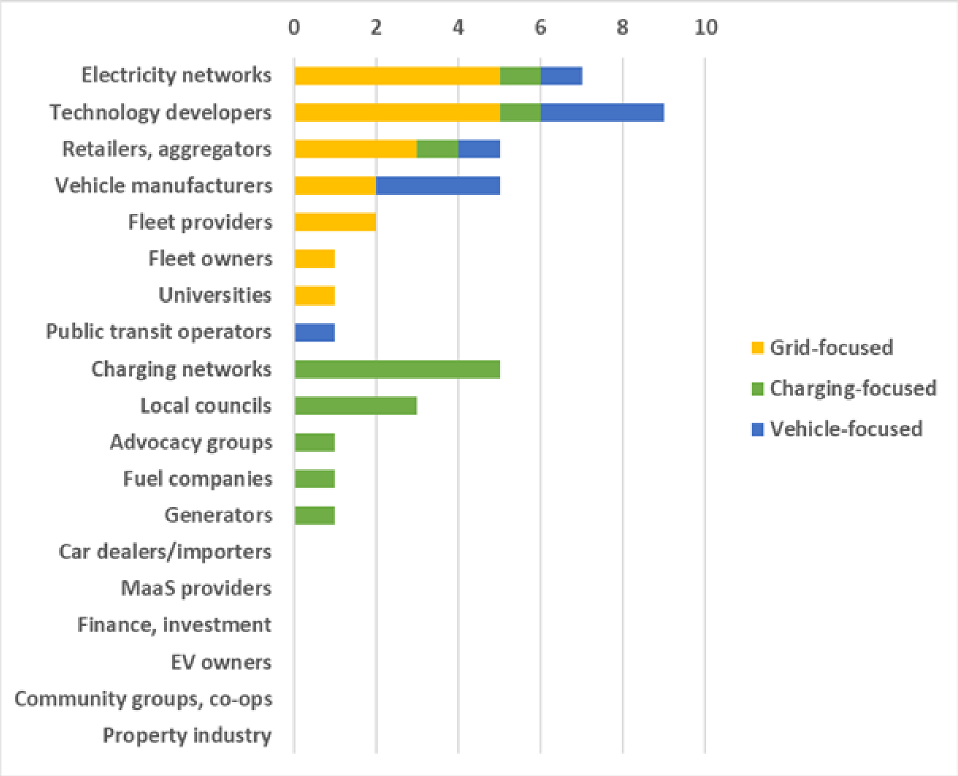


Figure 16 Estimated count of projects by partner type and project grouping (refer Table 22). The list is based on that proposed in [125].

There are commonalities within the three project groupings and limited crossover. Networks and technology developers, and to a lesser extent retailers, are most represented in projects. These grid-focused projects tend to envisage systemic change through the demonstration of economic value. They achieve more efficient use of network and vehicle assets by incentivising holders to optimise (lower) their energy bill. They are therefore consistent with the top-down economic logic of the grid and tend to conceptualise people as consumers.

Community or end-user groups are not well represented in projects, but those that do exist provide an interesting contrast. Only the Electric Highway Tasmania project is built around the end goal of EV users, which is to achieve state-wide coverage of fast chargers. The Charging the Regions project, a charging project by Victorian Councils, provides another example that is aiming for charger coverage over a specific geographical area. These projects aim to make owning an EV a more feasible proposition for local people. In contrast, fast charging networks such as those built by Chargefox and Evie Networks are designed to connect capital cities via major highways – undoubtedly improving infrastructure for locals, but not serving local trips. Examples of localised perspectives can also be seen in community micro-grid and battery projects.

Charging-focused projects have limited partner involvement from grid stakeholders, despite potentially significant local grid impacts. There is therefore room for more integrated approaches such as Jolt's partnership with AusGrid [126].

Project are yet to engage potentially important and influential groups such as mobility-as-a-service (MaaS) providers (many of whom are comprised of owner-driver sole traders), car dealers and importers who operate at the crucial point of sale, property developers, and financial service providers. In addition to those represented in the figure, other important groups could include tourism and retail operators, and logistics organisations.

4.1.2 Sectors

This section examines Australian progress in terms of the main use of the vehicles that are included in the project. The use is linked to the vehicle class—light passenger vehicles are used for private and business transport, including for passenger transport such as taxi services. Light commercial vehicles have a greater range of uses in different business sectors and are also popular as private cars. Heavy vehicles are generally not used for private purposes). Further detail of these distinctions is also discussed in section 3.2.

Figure 17 shows how sectors are represented across all projects. By far most projects are aimed at vehicles that charge at home and are not part of a fleet, which corresponds to private vehicles and other light passenger and light commercial vehicles that are used in a similar way. This is partly driven by the fact that light passenger EVs form the most available class of vehicle, and because high speed public charging networks are generally oriented to long distance private travellers who infrequently use fast charging (see 3.2 and 3.3).

REVS and the Origin EV Smart charging projects cater to business pool vehicles – REVS solely involves fleet, whereas Origin is open to both these and private vehicles. The bus and business passenger vehicle projects shown in Figure 17 refer to upcoming public transport electrification projects and the Energy Freedom Solar EV which is envisaged as an autonomous passenger vehicle. There are no projects serving the commercial passenger vehicle sector (e.g. taxis and ride-hailing services).

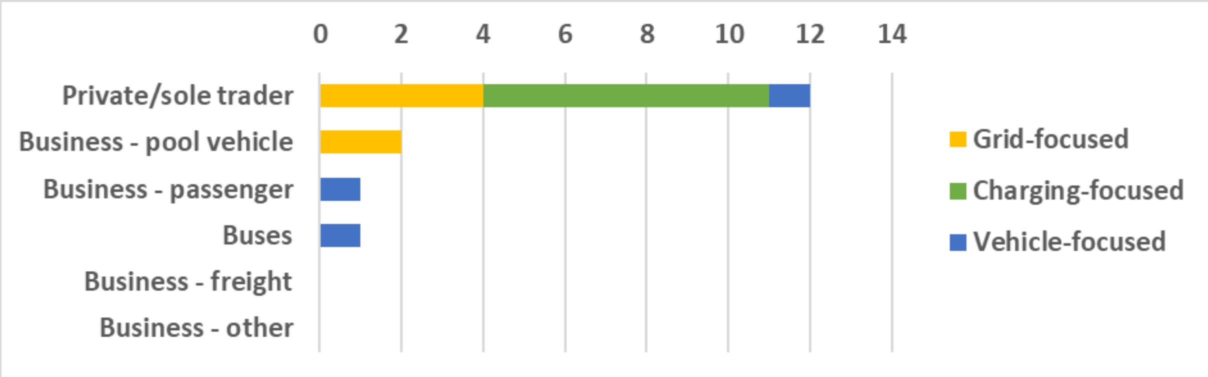


Figure 17 Estimated count of projects by the main use of the vehicle envisaged by the project.

When viewed in tandem with the prioritised vehicle classes shown in Table 7, it is clear that vehicle availability is a major factor driving project design. However even within sectors that use light passenger vehicles, projects focus on the private sector which is more reliant on home and workplace charging. There is therefore an opportunity for projects that take advantage of availability in light passenger vehicles but require business-focused charging solutions such as depot charging and solutions that suit vehicles that have minimal downtime and/or no depot. Vehicle uses such as taxis and ride-hailing are further complicated as the vehicles are largely owned by small businesses and sole traders. Internationally projects such as Optimise Prime have focused on fleets and home charging of vehicles used for business use [52].

The current lack of projects targeting buses is also a major gap, though some States and Territories have announced funding for electric bus projects. Freight is a major gap limited by vehicle availability.

4.1.3 Participation

Participation is central to realising a clean energy transition that is democratic, sustainable, socially shaped, responsible, just and responsive to public values and human needs [122]. The purpose of this section is to describe the participation frameworks currently represented in EV and VGI projects and to identify gaps.

Participation frameworks tend to be defined by the project partners. As discussed in section 0, the partners define the vision for the future and the change they deem necessary for getting there. They also define who can participate and by extension, who is excluded, and how that participation is orchestrated. Frameworks and collective participatory practices more broadly are hence comprised of the model of participation (how), the subjects (who), and the objects (what) as shown in Figure 19.

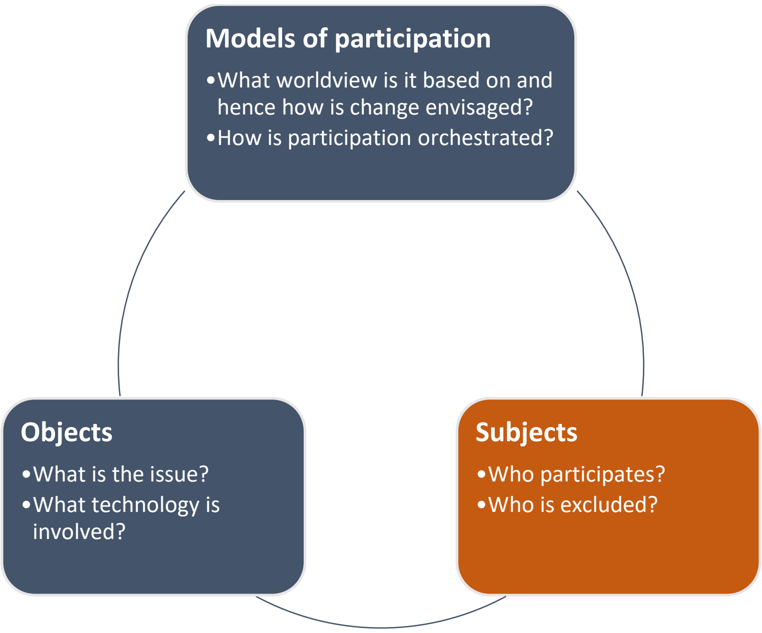


Figure 18: Defining participatory frameworks and practices (adapted from [122]). The discussion in this section focuses on the subjects.

Previous sections have already discussed worldviews and envisaged change and the sectors included, and the following section will discuss technology. Therefore, this section will consider how participation by the subjects is orchestrated: who is included and who is excluded.

In general, only grid-focused projects invite participation from people who are not partners. The Origin, AGL, Jemena and SmartCharge Qld trials all invited expressions of interest via a landing webpage, and offered inducements such as free chargers, bill credits or cash. Of these, only the Origin trial allowed businesses to participate. All were limited to EV owners and (with the exception of REVS) excluded premises where installation would be difficult or expensive, effectively limiting participation to residents of detached or semi-detached houses with driveways. This reveals potentially important gaps in participation in grid-focused projects: EV owners living in apartments, fleets, and others. Projects aimed primarily at overcoming installation challenges—clearly a major barrier—would help. Another gap is prospective EV buyers. If grid integration aims to improve the lifecycle cost of EV ownership, projects could produce interesting outcomes by targeting the point of sale (and partnering with car dealerships, for example).

Participation in REVS was only offered to ACT Government fleets. Inducements included cheaper vehicle leases and chargers. Fleets based in more difficult premises were not excluded, which resulted in some extra challenges to project delivery [55].

Charging-focused and vehicle-focused projects have not focussed on inviting participation from their eventual end users as yet. As a result, there are opportunities to bring different end user perspectives into infrastructure design. For example, designing charging sites that are accessible for disabled drivers. An example of how participation can facilitate better design is the Jolt Ad Revenue Funded Charging projects, where participating local councils have influenced site design so inappropriate advertising can be prevented [127].

4.2 Technology

Key Takeaways from this section

- There is relatively little variety in the technology being trialled in Australia at the moment. Potential opportunities include **heavy vehicles**, more expansive **V1G** and **V2G** trials, and grid services from **fast chargers**.

Figure 19 details the technology configurations used by projects in terms of vehicle classes, charging levels and VGI. All projects are intended and designed only light vehicles (primarily light passenger vehicles) except for State and Territory bus trials. Charging-focused projects are limited to on-route fast charging and, in the case of Jolt, mid-speed opportunistic or destination charging, and none incorporate VGI. Sections 3.3, 0 and 3.5 also provide a detailed discussion on the different technologies and their applications, covering charging, grid services and grid enablers.

Grid-focused projects involve private charging in homes or fleet bases. They include VGI methods that provide services to the grid: The Origin, AGL, Jemena and SmartCharge Queensland projects utilise V1G which provides peak shaving and intra-day balancing in the form of demand response. The AGL project also provides quasi-V2G in the form of FCAS, but not bidding into FCAS markets. REVS will provide V2G FCAS with market bidding. No grid-focused projects are used for behind-the-meter energy management. The ACE-EV project plans to be more expansive, encompassing behind-the-meter and grid-focussed value streams, though this is yet to be demonstrated in practice.

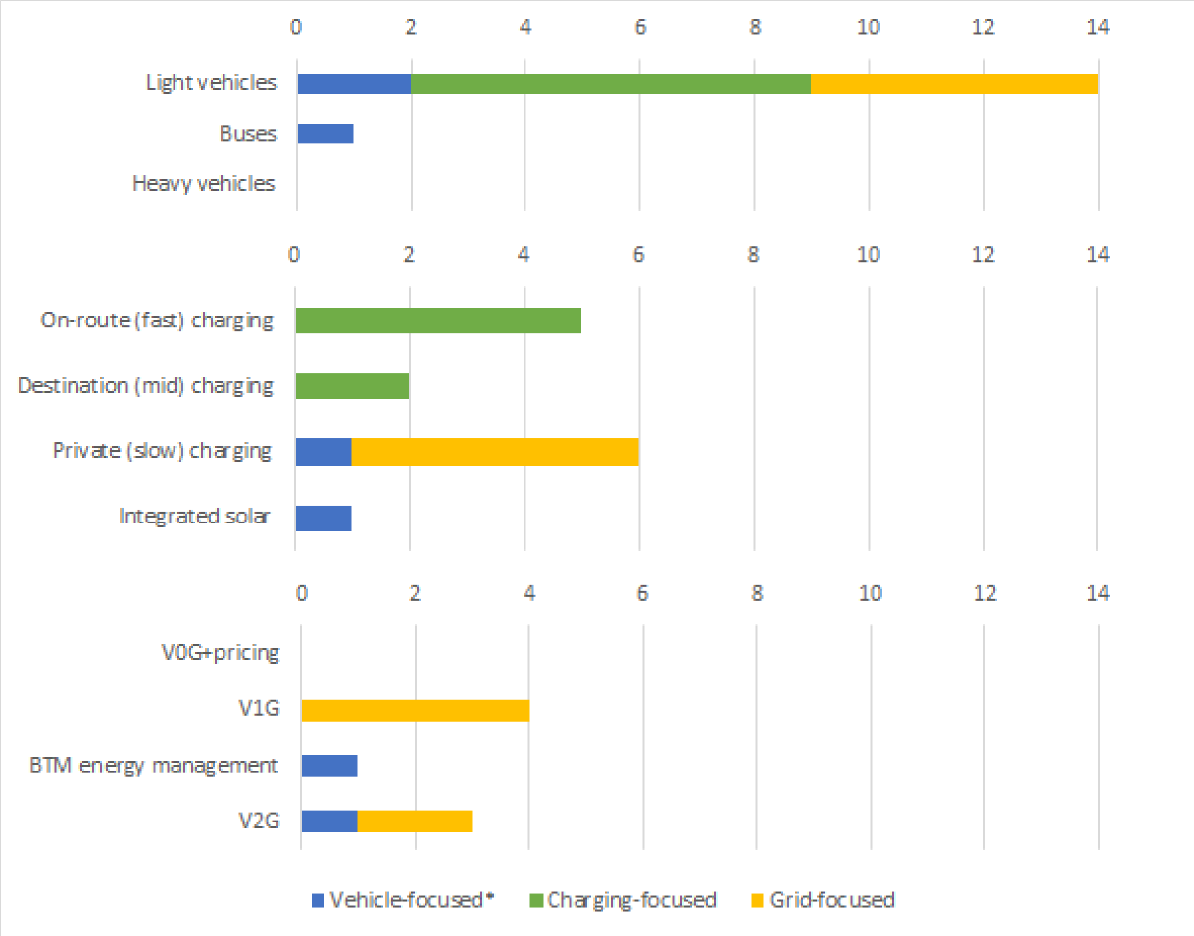


Figure 19: Technologies included in projects to date. *Note that vehicle-focused projects include bus trials with details yet to be confirmed.

There is therefore space for more technological variety in projects. The greatest gaps are in heavy vehicles across the board, although bus trials should go some way to closing this gap dependant on the level of public data sharing. Grid-focused projects involving faster chargers could apply dynamic operating envelopes and other new forms of grid integration. Likewise, expansions to the charging network could investigate grid services and pass on benefits to users in places like, for example, commuter car parks or shared charging facilities in apartment buildings.

4.3 Summary

This section has demonstrated that there is limited variety in projects to date. Variety needs to be considered not only in terms of the technology being offered, but whose perspective and vision the project is based around, including how they envisage change, and how participation in projects is limited and orchestrated. Variety and experimentation are essential to developing more appealing and equitable solutions which will contribute much-needed certainty and should lead to overall better solutions.

Table 23 Summary of gaps existing projects.

Partners	Few projects incorporate the visions and perspectives of end-users, local groups, automotive industry, and so on, mainly restricted to projects based on energy market logic.
Sectors	Opportunities to focus on owner-driver fleets, including MaaS, as well as projects centred around space and car parking such as tourist destinations, retail centres, public parking and property developers.
Participation	Participation models have focused on the easiest to reach groups. This neglects important groups with particular charging needs such as disabled drivers, regional drivers, apartment dwellers, fleets, and renters.
Technology	Charging-focused projects rarely incorporate VGI. There are major opportunities for VGI collaboration in heavy vehicles such as buses.

5 Gaps and recommendations

This report has used a top-down and bottom-up approach to mapping the landscape of EVs and VGI. In doing so it has defined many opportunities to enhance uptake. Uptake of EVs is not a series of discrete actions; a strategic approach will provide better outcomes. The framework for recommendations in this report, shown in Figure 20., is structured around three broad phases:

Define refers to the fundamental bases on which transitions are built, such as who or what are regarded as important, and what settings are in place from which change can be scaled up. Policy measures (outside the scope of this report) are very important in this phase, however projects can also create definition through variation in visions and participation.

Test is technology-focused, in that it aims to cultivate and embed new solutions and avoid the creation of new problems.

Build is focused on scaling technologies—grown from good fundamentals and incorporating foresight—and ensuring that insights and lessons are shared across a very broad and diverse range of stakeholders.

Our review suggests five groups of recommendations. These are summarised in Table 24 and expanded upon in the following sections.

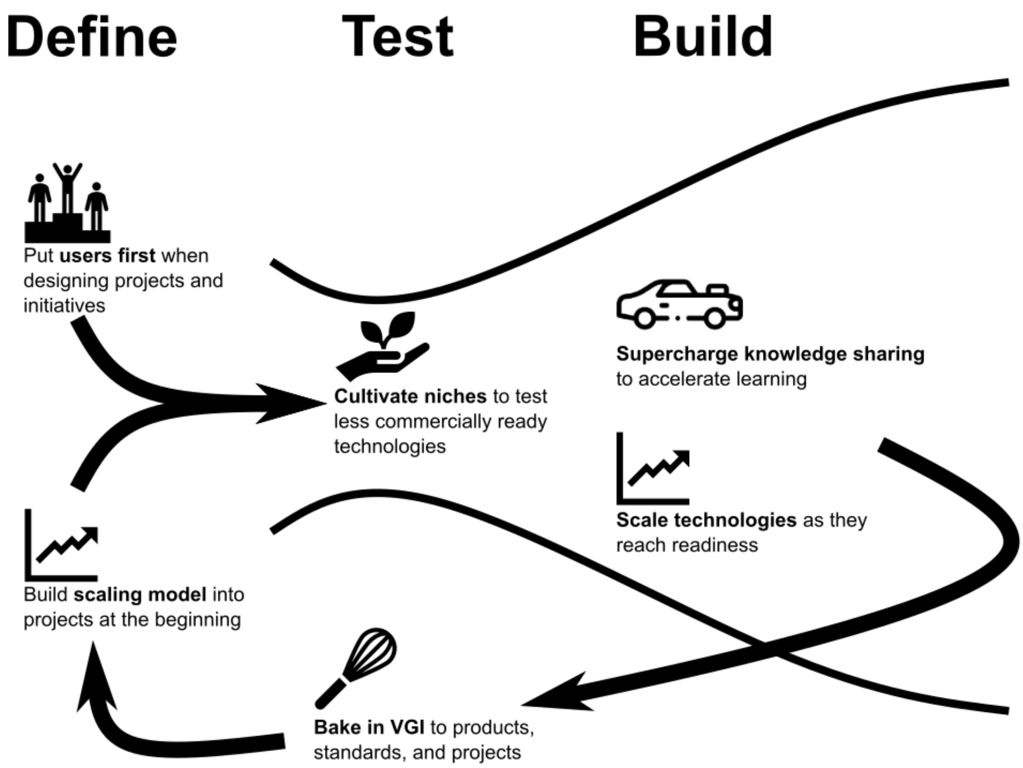


Figure 20 Recommendations framework

Table 24 Summary of recommendations groups

Group	Description
User first, Grid second	Many existing projects have been led by, and focused on, the needs of the energy system. Projects that focus on the visions and needs of end users or localised groups have greater potential to motivate adoption. Potential focusses for new projects could be hard-to-reach groups such as renters, apartment dwellers, disabled drivers, or geographically contained groups such as EV user communities and councils. Similarly, solutions that encourage replacement of journeys with shared or smaller modes of transport.
Scale up	Technology follows a path from concept to implementation. Scaling is where technologies become part of business-as-usual. This features twice on the framework: • Before niches are developed • As technologies become ready for expansion In the initial part, aside from policy measures (which are essential), scaling involves determining the key risks and factors that will enable uptake. This may include financing options and reducing uncertainty. Using trials to get the fundamentals right ensures they leave their niches as ready to scale as best as possible. In the latter part, scaling involves activities that encourage uptake, build momentum and transition away from relying on public funding.
Cultivate niches	Niches are protected environments that enable testing of technologies. Importantly, how niches are defined and what is tested in them strongly influences how technologies are taken up (or are not taken up). This means it is important to survey the landscape and determine which potential niches exist but aren't being investigated.
Supercharge knowledge sharing	Knowledge sharing is the most important part of innovation projects (like those funded by ARENA). Most current knowledge sharing for ARENA funded projects involves reports and presentations. These products may be missing a significant portion of stakeholders (particularly those outside of the energy industry) who stand to benefit from learning from these projects. In addition, project data is often not made public in a usable format.
Bake in VGI	Vehicle Grid Integration (VGI) is expected to be needed in the future, regardless of the electrification journey. All EV projects should include consideration of the most appropriate VGI, which can then be implemented, to avoid creating problems. Charging infrastructure projects in particular could benefit from this approach

5.1 User first, grid second

It is important to start with the user in any initiative, and vehicle electrification is no exception. Most EV projects to date have focused on market-based approaches to resolving grid issues with EVs. These projects have targeted easier to reach customer groups – largely private EV owners that already have an EV, and a place to park and charge it. This group of recommendations aims to bring users to the centre of electrification efforts.

Fair access to new technologies and their benefits, as well as variety in technological solutions, is imperative to a successful transition. Putting users first leads to greater variety of solutions that suit more people.

What does success look like?

Success in this group looks like initiatives that aim to solve problems for end users, such as:

- Projects that focus on hard-to-reach groups such as renters, apartment dwellers, and disabled drivers.
- Projects defined by geographically contained groups such as user communities and councils.
- Solutions that encourage substitution with smaller-scale transport options.
- Projects that implement an agile approach and co-design solutions with users.
- Inclusion of social science research in projects.

Example initiatives

- Public charging projects that address needs defined by local groups – Charging the Regions and Electric Highway Tasmania are good examples.
- Exploring the benefits and barriers to EV ownership for disabled drivers.
- VGI to meet customer defined behind-the-meter goals (such as net zero energy or certain pricing outcomes).
- Meeting the charging needs of owner-operated commercial passenger vehicles (taxis and similar).
- Innovative charging solutions for EV ownership without driveway ownership.

What people told us

Feedback on this group had two themes: Specific actions and projects that would provide useful tools for groups of users and process feedback that could improve how projects are scoped and delivered.

The common themes were:

- Improving charging experience (e.g. “tap and go” charging).
- Increasing uptake of customer-focused technology (such as behind-the-meter optimisation towards customer-defined goals).
- Do projects in a more agile way where methods and outcomes are explored as part of the project.
- Focusing on values beyond financial.
- Focusing on mid-sized organisations.
- Focusing on disabled and disadvantaged customers.

5.2 Scale up

Technology often has a fraught path between trial and large-scale adoption. There are many mechanisms that must operate successfully for this to happen. Two of these are the focus of this group of initiatives:

- The transition from grant to standard funding models.
- Business processes and standards.

Grant funding (such as provided by ARENA) is important in creating a “safe space” for innovation to occur. However, technologies need to be able to procure funding from standard sources to scale. It is important to consider how this will occur early on in niche creation. This may mean including key risks from financiers in project scope, so that the project outcomes address fundability risks. Business processes similarly need to integrate technology as it reaches mainstream. This means that processes become smoother and more integrated.

What does success look like?

Success in this group focuses on using trials and projects to establish the right set of fundamentals and providing support for technologies to build momentum once they mature. This could include:

For early-stage innovation

- Engaging prospective financiers in innovation projects prior to starting.
- Involving more transport sector stakeholders in trials, for better innovation and avoiding unintended consequences.
- Encouraging greater experimentation from networks.
- Building process outcomes into projects.

Scaling

- Expanding infrastructures and supply chains to address known barriers to uptake, whilst also directing public funding to less viable projects (such as regional charging).
- Building a clear exit path from innovation to open market funding.
- Cross-organisation collaboration to remove roadblocks and encourage uptake.

Example initiatives

Early-stage innovation

- A process to engage with financiers to determine key risks and factors that should be considered in trials to ensure fundability.
- Cross-cutting analysis of existing trials to find common roadblocks and enablers.

Scaling

- Expand public charging infrastructure to the levels required for mass usage, including on-route, destination, commuter parking and other forms of charging.
- Projects that increase choice and supply in the new and second-hand light vehicle markets.
- Reduce fragmentation such as plug standards.
- Innovative charging solutions for EV ownership without driveway ownership.

What people told us

Feedback in this group had two themes: What was ready for scaling, and how scaling could be encouraged.

- Charging in general (home, destination, and fast charging) was felt to be ready for scaling
- Tools to help auditing or selecting vehicles for electrification.
- Considering other non-monetary things that could enable uptake (e.g. access to facilities).
- Baking in scaling early in niche development so that technologies are funding ready as they leave trial.
- Networks need to be more willing to engage with innovation.

- Involvement of transport and urban planners is essential – the energy industry does not understand transport.

People also identified very strong need for policy leadership in the EV transition, for example in building standards, Australian Design Rules regarding truck dimensions, and reforming fuel excise and EV road user charges for fairness and encouraging positive change.

5.3 Cultivate niches

Niches are the engines of early-stage technologies. They create a safe space which allows demonstration with more room for innovation that is insulated from normal business processes. Much of this report aims to define which potential niches exist but are yet untested. Consultations then discussed what the most important new projects in developing EV and VGI technology might be.

What does success look like?

Success in this group looks like diverse niches being tested that address existing gaps in EVs availability and adoption. A number of vehicle types, especially specialised non-freight carrying vehicles, heavy freight and buses, have negligible uptake of zero emissions technology to date. Equally, however, there is uncertainty regarding what technology (usually between hydrogen fuel cell and EV) is fit for different purposes. Projects are needed to test the gamut of implementation factors and reduce uncertainty for potential users. This could look like:

- Projects devised in partnership with organisations that are potential users, such as councils, public transport agencies and logistics companies.
- Systematic infrastructure planning for logistics or public transport.
- Agile approaches to project design.

Example initiatives

- Specialised and high-visibility vehicle electrification (such as rubbish trucks).
- Freight vehicles and depot/on-route charging.
- Projects that directly compare hydrogen fuel cell and EV heavy vehicles.
- Conversion of internal combustion vehicles to zero emissions rather than scrapping them Initiatives that focus on developing substitution options (e.g. cars to electric scooters).

What people told us

Common feedback in this group was around risk appetite. Currently projects funded by ARENA must have a relatively low risk profile, which makes more uncertain or novel technologies hard to fund. Other feedback was around which vehicles make the best niches to build. Feedback indicated high mileage, visible vehicles such as buses, freight, taxis and ride-hailing services may make good targets.

5.4 Supercharge knowledge sharing

Knowledge sharing is rightly an important part of the ARENA knowledge and innovation model. However, our consultations revealed that there is a widespread and strong feeling that it is currently not meeting its potential to engage, connect and inspire across a broad audience. The data generated through projects is not published in a form that industry can make good use of. This is especially an issue for EV and VGI projects that involve the transport sector, which has not previously been involved in energy projects.

What does success look like?

Success in this is described in two streams: translation and open data.

Translation means bridging the gap between knowledge and action through the analysis and communication of project data. Because EVs and VGI involve technical, economic and social dimensions, it is essential that translation efforts are fluent in these fields, up to date with the most pressing questions, and able to deal with their complex interactions. A robust approach to knowledge translation would also consult stakeholders directly on their most important challenges and opportunities, and draw on international research and experience.

Universities engaging with multidisciplinary energy research are well placed to produce such outcomes. Investing in translation will ensure that projects feed into broader innovation processes and produce generalisable results.

Generalisability is about generating practical, day-to-day advice for stakeholders that is useful beyond the project it came from. For example, providing the tools to evaluate the real-world impacts of grid participation on batteries would empower fleet managers to assess and make decisions. This provides a resource that promotes action and is trustworthy.

Open data means cultivating an accessible and trusted data resource that services the EV landscape in Australia and works towards filling data gaps. For example, vehicle usage and charging data is not generally available outside opaque facts and figures quoted in reports. An open data resource allows users to generate insights that are relevant to their own innovation and research needs, and to be confident they are reliable. Data needs curation and to contain metadata to be useful, but the sort of data required depends on the use case. An open data resource would be useful for a wide range of stakeholders, ranging from start-ups to larger organisations and researchers with analytics capability.

Example initiatives

- Use of multidisciplinary and trusted knowledge sharing agents focused on answering pertinent questions and generating generalisable insights using a consultative approach.
- Open data platforms and greater emphasis in generating public data in projects.
- Engaging knowledge sharing events that are accessible and tailored to multiple industry and community groups.

What people told us

Knowledge sharing had widespread support amongst participants, but also frustration that it was not meeting its potential. For many, a better result meant knowledge sharing products that are framed for the benefit of the users of information, rather than meeting the reporting obligations of current projects. For instance, information that breaks through “sales pitches” and presents impartial information that helps in decision making processes. For some users, raw data allows them to generate their own insight. This requires appropriate curation and metadata, but these needs depend on the use case. For example, distribution networks might require location data and/or energy consumption profiles.

Some participants suggested overseas initiatives, such as those from the UK that intends to build public charger data available [128] as good examples of the sort of data platforms that were valuable.

5.5 Bake in VGI

Vehicle Grid Integration is widely expected to be required in the future (see sections 0 and 3.5). VGI is a common element in grid-focused projects today, which usually focus on overnight charging of passenger vehicles, most commonly using the charger to manage the charging process. However, VGI is not a central element in many other projects, significantly charging infrastructure projects.

Gaps in this space are around:

- Standardisation of charge management mechanisms.
- Extending the applicability of V2G.
- Integration of VGI into further contexts (such as microgrids and public car parks).
- Vehicle based VGI.

This expansion of VGI must be tempered with its additional cost and impact on customer choice. The cost of VGI may be unjustified if its ultimate use is too distant or speculative. Similarly, a poorly defined VGI standard can reduce customer choice, or prevent them from interacting with their vehicle in a way they prefer.

What does success look like?

Success in this initiative is when appropriate VGI is provided “standard” in products in the Australian market. In the short term this requires trialling VGI in more contexts and assessing the customer interface of this VGI.

Example initiatives

- Initiatives to assess the appropriate architecture (e.g. locus of control, consent) in collaboration with customers, and the energy and transport industries.
- Trials of VGI at public fast chargers that prioritise charging needs.
- Trials of resilience services from EVs (e.g. microgrids).
- Trials of destination and long-term parking V2G or VGI.
- V2G trials that are more expansive of use case (e.g. within buildings or standalone power).

What people told us

VGI was universally felt to be important amongst stakeholders. Key tensions are around how control ought to be implemented. Some stakeholders felt that the locus of control needed to remain with the customer, while others felt the energy system needed to retain ultimate control.

VGI was felt to currently be beyond most customer’s grasp. EVs and charging is too new to people, never mind VGI. Stakeholders felt that people would be in a better position to understand VGI when they had experienced living with an EV for a while.

Stakeholders noted that projects should be careful of unintended consequences, such as encouraging use of public parking (as opposed to leaving the car at home).

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