

N1 Research Project

My V2X EV: Informing strategic electric vehicle integration

Final Report



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My V2X EV: Informing strategic electric vehicle integration.

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The authors of this report would like to respectfully acknowledge the Traditional Owners of the ancestral lands throughout Australia and their connection to land, sea and community. We recognise their continuing connection to the land, waters and culture and pay our respects to them, their cultures and to their Elders past, present and emerging.

What is RACE for 2030?

RACE for 2030 CRC is a 10-year co-operative research program with AUD350 million of resources to fund research towards a reliable, affordable, and clean energy future. racefor2030.com.au

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Executive Summary

The uptake of electric vehicles (EVs) in Australia is expected to increase in the coming years. Uncontrolled charging of these EVs can lead to substantial growth in electricity demand during peak times, putting the already stressed grid under further pressure. Future EV models are expected to be equipped with vehicle-to-everything (V2X) technology (e.g. vehicle-to-grid (V2G) and vehicle-to-home (V2H)), which can support households and the grid through bi-directional charging when required. Developing a regulated V2X system can mitigate the challenges of high EV penetration.

Despite potential advantages, implementing V2X has several technical, market and regulatory challenges. Standardising every aspect of EV-integrated infrastructure is essential for its efficient operation. This report provides i) the findings of the consultation undertaken on managed charging to inform the design of future demonstration projects, and ii) a summary of factors related to EV-grid integration to create initial recommendations for a pathway towards this integration.

Costs and benefits of V2X

The costs and benefits of V2X technologies vary across stakeholders such as EV owners, manufacturers, electricity transmission network service providers and distribution network service providers (TNSPs and DNSPs), and the general public. Benefits, and thus the engagement of EV owners in V2G, require appropriate demand-response and V2G tariff policies. A comprehensive tariff study is required to consider results from current trials, predictions for future EV uptake and the mobility behaviour of various user groups. Battery degradation is a concern for EV owners, potentially causing them to hesitate in participating in V2G and instead choose more transparent applications, such as vehicle-to-load (V2L) or V2H. Compared to V2H, V2G has several economic and technical advantages—owners have direct access to wholesale energy markets, and grid operators benefit from a virtual power plant able to provide ancillary services on a large scale.

However, V2G in Australia has some challenges. One is the lack of a regulatory framework for the implementation of technologies to enable EV owners to participate in different value streams, such as the frequency control ancillary services (FCAS) market. More Australian-based research and modelling is required to simulate different types of regulatory schemes that can estimate the economic benefits for EV owners, the technical and economic benefits for grid operators, and benefits for the wider community.

New regulations and standards are required

EVs will interact with the electricity system at several points. Depending on whether an EV will be (a) charging from the grid or (b) discharging to the grid, this will impact on retailers, networks and wholesale market participants and outcomes. Large-scale EV adoption as projected by AEMO will not only increase daily demand significantly but the intraday distribution of charging activities (assuming least-cost tariff-based charging optimisation) will also influence prices and National Electricity Market (NEM) infrastructure requirements. EVs will be mostly connected to the grid from behind the meter. The key legal questions that will have to be addressed in the future will include whether EVs can and should interface with the electricity market other than as consumers, to what degree this interaction needs to be facilitated, and by whom.

EVs will interface with the distribution network rather than the transmission network. Key questions to be answered include: How can legislation incentivise DNSPs to build the type of grid best suited to accommodate electric vehicles, and how will revenue or tariff settings influence these choices? Is a change in the roles and responsibilities of network providers required, or do new roles need to be created?

Gaps in compliance and interoperability standards

It is crucial that EVs, chargers, electricity networks and retailers, homes, and communication and control devices are 'interoperable': they all need to connect, communicate and work together effectively for the benefit of customers. The barrier to achieving system-level coordination and integrating EVs into power grids is that no current regulatory framework in Australia stipulates transparent communication, data exchange and interoperability procedures. The AS/NZS 4755.3.4, drafted in 2013, includes an interface specification for remote

agents that describes interactions and operating procedures for charging/discharging controllers for electric vehicles and other energy storage devices. However, this draft was never finalised or implemented. We need to conduct a comprehensive assessment before adopting any interoperability policy.

Infrastructure assessments are required

The increased share of renewables in the energy mix has reduced system inertia, making frequency regulation more challenging. Over the past few years, several trials have been conducted in Australia investigating the role of renewable energy generators, battery energy storage systems and virtual power plant participation in frequency regulation. Due to their large battery capacity and fast-response power converters, EVs are suitable for frequency regulation. In Australia, the frequency is regulated by the FCAS market and its related ancillary services. To play a meaningful role in this environment, EVs with V2X capabilities need to be officially recognised as active participants in the FCAS. Appropriate regulatory platforms and efficient market mechanisms are required to facilitate the entry of aggregated EVs into the FCAS market. EV aggregators should also develop an appropriate strategy to effectively contribute to FCAS and achieve maximum benefits while considering several uncertain parameters.

In this project, a national stakeholder consultation and the formation of an industry reference group (IRG) with key stakeholders helped to inform key research questions and the design of potential demonstration projects for EV grid integration where a range of benefits can be delivered. The key learnings from the consultation were that:

- There has been an over-focus on early user groups.
- Projects are needed that can unlock scalability/replicability.
- The immaturity of V2G brings risks, but trials of bi-directional charging (V2H, V2B) could be worth exploring if the risks can be managed.
- An approach is needed that integrates the behavioural aspects and price signals of V2G, along with energy system impacts and network impacts.
- The costs and benefits to customers/businesses remain to be understood for specific customer use cases.

We need to leverage existing projects or capital works/asset investments to accelerate the path to replicability and scalability.

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1. Introduction

Electric vehicles (EVs) are gaining popularity in Australia. Around 20,665 EVs were sold in 2021, representing 2% of all new light vehicles compared to 0.78% in 2020. Nearly 76% of these sales were battery electric vehicles (BEVs), while plug-in hybrid electric vehicles (PHEVs) accounted for approximately 24%.^{1,2} Despite the growing sales of EVs, Australia still remains substantially behind the rest of the developed world when it comes to EV use. In contrast, Norwegians are among the world’s leading adopters of EVs, which comprised 74% of all light vehicles sold in Norway in 2020. Australia also has a smaller market share than the US (2.3%), the UK (10.7%) and China (6.2%).

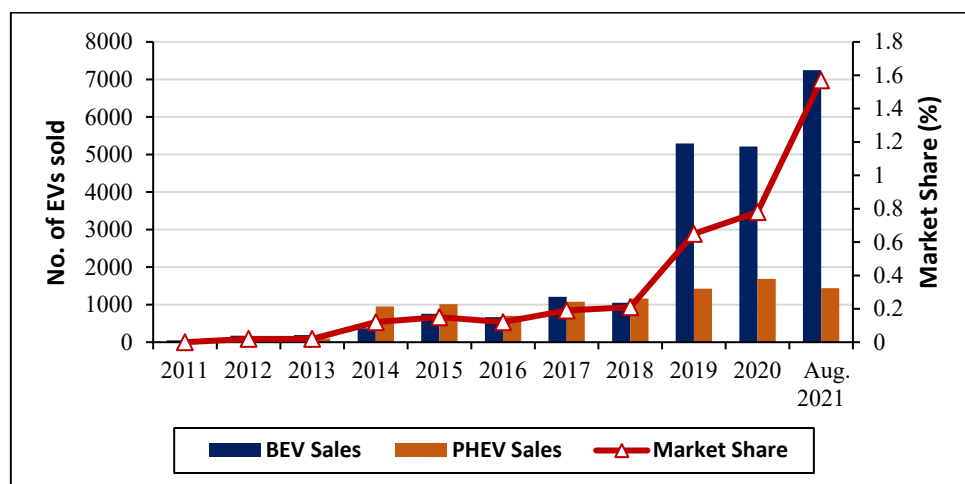


Figure 1. Sales of EVs in Australia¹

While EV sales have increased significantly over the last few years in Australia, only 0.12% of the country’s light vehicles are electric. New South Wales and Victoria have the highest number of EVs in Australia, while the ACT is the region with the highest penetration at a rate of 0.31%, followed by South Australia with 0.16%. With the introduction of new EV models—some of which will be cheaper than the current offerings—the demand for EVs will increase in the coming years.³

In 2023, most car manufacturers around the world are focusing on e-mobility and making substantial investments in EV development. Many manufacturers have announced their intention to convert to 100% EVs within the next few years. General Motors (GM) and Audi plan to have 30 EV models available in 2025, while Hyundai will offer 23 models and Groupe Renault will have 30 models. The Volkswagen Group will introduce 70 new EV models by 2028.⁴ In Australia, 31 EV models are now available from 12 different manufacturers, with 14 models priced below \$65,000. Plug-in hybrid vehicles, with 17 models, continue to represent a larger market share than battery EVs. During the period of 2021 to end of 2022, 27 additional EV models were planned to be available on Australian

¹ Electric Vehicle Council. (2021, August; 2022, March). State of Electric Vehicles. <https://electricvehiclecouncil.com.au/state-of-evs-october2022/>

² ENERGEIA. (2018). *Australian Electric Vehicle Market Study*. ARENA and Clean Energy Finance Corporation. <https://arena.gov.au/assets/2018/06/australian-ev-market-study-report.pdf>

³ Lavieri, P., & Domenech, C. B. (2021, April 28). *Electric Vehicle Uptake and Charging. A Consumer-focused Review*. University of Melbourne. <http://dx.doi.org/10.13140/RG.2.2.17678.08009>

⁴ International Energy Agency. (2020). *Energy security: reliable, affordable access to all fuels and energy sources*. IEA. <https://prod.iea.org/topics/energy-security>.

roads. It is important to note that, despite the increase in the number of models available, the Australian market will remain behind other developed countries; in the UK, for example, over 130 EV models are already available.^{5,6}

1.1 Charging infrastructure

Investing in charging infrastructure is essential to ensuring that EV adoption continues to grow. During the past few years, there has been a significant increase in charging facilities, including a 24% annual growth rate in DC fast chargers and ultra-fast chargers (50 kW and over), and a 23% annual rise in standard chargers. Australia currently has more than 3,000 public charging stations installed at over 1,650 locations across the country, including 470 DC fast chargers located at 250 sites.¹ Further investments in charging stations are expected to facilitate this growth.

Table 1. Number of standard and DC fast-charging stations in Australia

States	ACT	NSW	NT	QLD	SA	TAS	VIC	WA	National
DC fast	10	181	2	84	27	18	115	33	470
Standard	48	836	28	402	256	82	607	272	2531

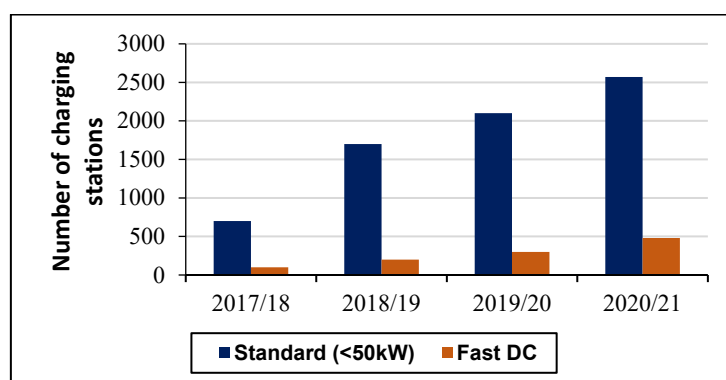


Figure 2. Number of charging stations in Australia⁷

Australia's rather slow EV uptake is the biggest barrier for investment in charging infrastructure.⁸ Without an increase in the utilisation of charging infrastructure, investing in charging stations would be less justifiable. The number of EVs per public charger currently stands at 7.21 across Australia.⁹ Although this average does not indicate how different charging stations are used, it illustrates some of the business challenges that infrastructure investors may encounter. Several leading companies are providing charging infrastructures in Australia.¹⁰ These include:

⁵ NRMA. (2020). *EVs: Accelerating adoption in Australia*. <https://www.mynrma.com.au/-/media/documents/evs/evs-accelerating-adoption-in-australia.pdf>

⁶ EV Hub. <https://ev-hub.com.au/ev-available-in-australia>

⁷ Electric Vehicle Council. (2021, August). *State of Electric Vehicles*. <https://electricvehiclecouncil.com.au/reports/state-of-electric-vehicles-2021/>

⁸ PriceWaterhouse Coopers. (2019). *Australia's road to zero transport emissions: Australia's road to a clean transport future*. PWC. https://www.pwc.com.au/government/Australias-road-to-zero-transport-emissions_1.pdf

⁹ Electric Vehicle Council. Australian EV charger map. <https://electricvehiclecouncil.com.au/about-ev/charger-map/>

¹⁰ Electric Vehicle Council. EVs available. <https://electricvehiclecouncil.com.au/about-ev/evs-available/>

- ABB
- Chargers Direct
- EGen Electrical
- eGo Dock
- Electromotiv
- EVERY
- Evie Networks
- EVolution
- EVSE
- FIMER
- Gemtek
- JET charge
- NHP Electrical Engineering
- Schneider Electric
- Siemens
- Southern Sustainable Electric
- Tritium
- Zenobe Energy

Currently, electric vehicle batteries that can provide a driving range of 200-400 km and beyond before recharging are becoming more common. However, based on a recent Australian study, over 99% of daily trips are under 50 km in distance, meaning a vast majority of vehicle use is within the range of almost all EVs.¹¹ In some cases, charged vehicles stay at the charging station—and therefore connected to the grid—for longer than the vehicles battery requires to reach full charge. This means that during times where the vehicle is not in use, these stationary vehicle batteries could be used to feed energy back in support of the grid or for use by some service outside the vehicles driving operations.¹²

1.2 Vehicle-to-everything (V2X)

V2X refers to the interaction between vehicles, other entities, and the infrastructure of a smart city. It can be in the form of vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), vehicle-to-home (V2H), vehicle-to-grid (V2G), vehicle-to-network (V2N), vehicle-to-building (V2B) or vehicle-to-load (V2L). Regarding the interaction of EVs with the power grid—which is the focus of this report—V2G, V2H and V2L are considered. In this context, EVs are considered mobile energy storage systems that can locally support the power grid to balance supply and demand. Similar to battery storage systems, these technologies can contribute to the grid by load-leveling, voltage and frequency regulation, and peak load-shaving. However, several technical and economic challenges need to be solved to achieve this benefit. Based on the literature and international practices, these challenges have been reviewed here, and research gaps to address the challenges and requirements of the implementation of V2G in Australia have been proposed at the end of this report.

The potential of V2G is influenced by EV availability, which depends on the owner's acceptance of this new technology, along with driving behaviour, willingness to participate in V2G programs, system readiness (e.g. charger availability), technical constraints (e.g. battery degradation), market readiness, technical standards and regulations. V2G technology is a flow of *energy, information and money* between EV owners, aggregators and the power grid to create a stable balance between demand and supply. V2G can provide valuable support to the grid for voltage and frequency ancillary services and better demand-side management, thus compensating for the variability of renewable energy resources and reducing the infrastructure upgrade cost compared to the G2V-only cases. Despite these opportunities, implementing V2G has clear consequences and costs for EV owners and grid operators, such as battery degradation, the need for sophisticated communication between EVs, and grid infrastructure upgrades. There are also social, political, cultural and technical obstacles.¹³ Failure to optimally integrate V2G may result in overloaded transformers, decreased systems efficiency, and cause voltage and frequency perturbations, resulting in disruptive harmonics in the grid.

Unless it is well managed, V2G may cause a reduction in power quality. Power being injected into the grid via a converter can cause voltage compliance issues, harmonics, and overloading of transformers. Traditionally, utility companies have utilised devices such as voltage regulators, capacitor banks and transformer taps to improve power quality. EV smart-charging can be used as an alternative to alleviate power quality issues, with its advantage

¹¹ Gong, S., Ardeshiri, A., & Rashidi, T. H. (2020). Impact of government incentives on the market penetration of electric vehicles in Australia. *Transportation Research Part D: Transport and Environment*, 83, 102353. <https://www.sciencedirect.com/science/article/abs/pii/S136192092030540X?via%3Dihub>

¹² Ravi, S. S., & Aziz, M. (2022). Utilization of Electric Vehicles for Vehicle-to-Grid Services: Progress and Perspectives. *Energies*, 15(2), 589. <https://doi.org/10.3390/en15020589>

¹³ Ibid

being flexibility. A US study shows that personal vehicles are engaged in travel on average only 4-5% of the time, sitting in home garages or parking lots the rest of the day.¹⁴

This project aimed to remove the barriers and enable opportunities for V2X, develop a path to implementation through technical solutions, and create partnerships for demonstrations. The research will inform the pathway to a rapid scale-up of V2X-enabled EVs. Stage 1 of this project, which is reported here, has two work packages (WPs). Work package 1 (WP1) undertook consultation in relation to managed charging to inform the design of future demonstration projects to build confidence in V2X and support an increase in uptake. WP2 conducted research to create initial recommendations for a pathway towards grid integration of EVs. The focus of this stage was to identify high-impact, high-priority challenges of EV-grid integration, particularly relating to V2X.

To address these objectives, various technical and economic aspects of the V2G concept were reviewed based on the literature and international practice. Costs and benefits from this technology to different stakeholders are revisited in Section 2, along with current regulations, how they impact the V2G uptake, and how research can help to update them. Important changes to technical standards that are required to make the EV ecosystem V2G-ready are explained in Section 3. In Section 4, a national consultation process performed as part of this project is reviewed, in addition to recent national and international trials in relation to V2G. The report concludes in Section 5 with a set of research questions to address challenges and barriers for V2G uptake in Australia.

¹⁴ Foundation for Traffic Safety. (2021, April). *New American Driving Survey*. <https://aaafoundation.org/wp-content/uploads/2021/04/New-American-Driving-Survey-Report-April-2021-1.pdf>

2 Costs, benefits and potential value streams for V2G services

The interaction of EVs with the power grid will happen at several points and impact EV owners, retailers, network operators and wholesale market participants. Large-scale EV adoption, as projected by the Australian Energy Market Operator (AEMO), will not only significantly increase daily demand: depending on the intra-day distribution of charging activities (assuming least-cost tariff-based charging optimisation), it will also influence prices and NEM infrastructure requirements. Intra-day charging and discharging patterns will be a key factor in determining what type of new generation and storage technologies (e.g. solar PV or batteries) will be required, and where they should optimally be located to minimise grid congestion.

2.1 The costs and benefits of different types of V2X

One of the objectives of V2X is to generate revenue for EV owners. In the context of the electricity market, this can be done through active control and advanced scheduling of EV bi-directional charging.¹⁵ EV owners can charge their vehicles during the day rather than at night and take advantage of cheap solar energy. With a battery fully charged, these EVs can support the local household peak evening consumption using V2H or sell electricity to support the grid using V2G. Distribution Network Service Providers (DNSPs) also benefit from this scenario because it can reduce and shift the peak energy demand and provide a flexible back-up power supply for consumers and ancillary services. Both EV owners and DNSPs can still benefit from uni-directional charging (G2V) as it can provide flexibility through smart-charging and scheduling algorithms, but this option has limited capacity to provide grid support and back-up power.

Vehicle-to-load (V2L) can provide emergency back-up power to a critical load in case of an outage or provide an alternative source of electricity to a diesel generator in off-grid areas. In its simplest form, V2L already exists commercially as some EVs come with a standard AC power outlet built in. V2H is slightly more complicated than V2L because it seeks to use an EV as an emergency power back-up for an entire home in addition to reducing the household's energy consumption from the grid during peak hours. V2H would work best in combination with rooftop solar, where time-of-use (ToU) or peak/off-peak tariffs exist. However, economic analysis and simulations need to be undertaken in Australia to assess the economic benefits of V2H considering the costs of the bi-directional charger, home energy controller and rooftop solar dedicated to charging the EV battery, as well as the degradation of the battery. Currently, a bi-directional charger in Australia costs up to \$10,000. Even with ToU tariffs, these large up-front costs will substantially reduce the economic benefits of V2H. Nevertheless, this option may still be of interest to a limited number of consumers who wish to be independent of the grid. As V2H technology scales up, the costs are likely to come down.

Vehicle-to-building (V2B) is similar to V2H but aggregates several EV batteries to optimise the energy consumption of a larger building (e.g., an apartment complex or office building). V2B can reduce a building or an industrial site's capacity/demand charges and thus the cost of inductive loads. The buildings can also benefit from V2B by using power factor correction, reactive power control and voltage regulation. Vehicle-to-grid (V2G) has the advantages of V2B, but on a much larger scale. V2G has the largest potential for economic benefits because it offers direct access to wholesale energy markets and could provide ancillary services.¹⁶ Given the price peaks that can occur in the wholesale market, V2G is perhaps the only bi-directional operational methodology that is currently economically viable.

¹⁵ Thompson, A.W., & Perez, Y. (2020). Vehicle-to-Everything (V2X) energy services, value streams, and regulatory policy implications. *Energy Policy*, 137, 111-136. <https://doi.org/10.1016/j.enpol.2019.111136>

2.2 V2G costs, benefits and value streams

Stakeholders available in a V2G market include EV owners, EV manufacturers, energy aggregators, electricity generators, network operators and the general public¹⁶, with different levels of costs and benefits. Costs incurred by EV owners will include the installation cost of a bi-directional charging system, loss of charging autonomy, and the possibility of additional battery degradation. DNSPs may face additional regulatory and administrative costs, the cost to enable new charging infrastructure, data communications, and the development of smart algorithms. EV manufacturers will incur a cost to enable EVs to support bi-directional charging. Furthermore, V2G services will compete with battery energy storage systems (BESS) such as the Tesla Powerwall. V2X systems have similar characteristics to BESS and can provide most BESS services if aggregated.¹⁷ V2G can provide a dispatchable resource for the AEMO; it can also, however, worsen the minimum demand reduction. Table 2 outlines various potential costs and benefits of V2G to different recipients. While there are many examples of international trials that have benefitted both EV owners and grid operators¹⁸, the quantitative savings would be difficult to compare to the Australian energy market structure and the Australian lifestyle. Local Australian trials are required to fill this knowledge gap, including extensive V2G modelling and testing of battery degradation.

Table 2. V2G EV costs, benefits, and potential stakeholders, including transmission network service providers (TNSPs), distribution network service providers (DNSPs) and original equipment manufacturers (OEMs), as well as people and organisations, etc. (Jones. L et al. 2021, adapted)¹⁹

Stakeholders	Cost	Benefit
EV owners, fleet managers	<ul style="list-style-type: none"> • Installation of the bi-directional charging system • Loss of charging autonomy • Possible degradation of the EV battery 	<ul style="list-style-type: none"> • Reduced costs/increased revenue • Empowerment, as users could participate in the energy market • Appeals to sustainability values • Backup power for emergency and normal uses
Aggregators/energy retailers and generators	<ul style="list-style-type: none"> • Additional regulatory and administration costs such as tariff reform • Additional hardware and software infrastructure 	<ul style="list-style-type: none"> • Service providers can offer a new product that appeals to sustainability values and that assists customers with bill management. • Better utilisation of renewable energy resources
Transmission network service providers (TNSPs), distribution network service providers (DNSPs), energy market operators	<ul style="list-style-type: none"> • Additional regulatory and administration costs • Cost to enable new charging infrastructure and data collection, storage and sharing systems • Expanding AEMO visibility and controllability over the distribution grid 	<ul style="list-style-type: none"> • Balancing intra-day supply and demand • Providing frequency control, voltage control and power factor correction services • Avoiding network congestion and deferring network upgrade investments • Improving the network security and additional fault recovery services • Providing networks with charging data to improve network planning

¹⁶ Jones, L., Lucas-Healey, K., Sturmberg, B., Temby, H., & Islam, M. (2021, January). *The A to Z of V2G*. REVS/ANU. <https://apo.org.au/sites/default/files/resource-files/2021-02/apo-nid311127.pdf>

¹⁷ Thompson, A.W., & Perez, Y. (2020). Vehicle-to-everything (V2X) energy services, value streams, and regulatory policy implications. *Energy Policy*, 137, 111136. <https://doi.org/10.1016/j.enpol.2019.111136>

¹⁸ Frick, N.M., Price, S., Schwartz, L.C., Hanus, N.L., & Shapiro, B. (2021, February). *Locational Value of Distributed Energy Resources*. Lawrence Berkeley National Laboratory, California, United States. <https://doi.org/10.1109/TSG.2019.2921205>

¹⁹ Jones, L., Lucas-Healey, K., Sturmberg, B., Temby, H., & Islam, M. (2021, January). *The A to Z of V2G*. REVS/ANU. <https://apo.org.au/sites/default/files/resource-files/2021-02/apo-nid311127.pdf>

Original equipment manufacturers (OEMs)	<ul style="list-style-type: none"> • Enable EVs to support bi-directional charging • Competition with home battery energy storage market 	<ul style="list-style-type: none"> • Offers a new product that appeals to sustainability values and that assists customers with bill management
General public	<ul style="list-style-type: none"> • Changing mindsets about EVs, from mobile electricity storage/consumer to mobile storage that supports the grid 	<ul style="list-style-type: none"> • Energy bill savings for everyone (not just EV owners) • Assist in the transition towards renewable energy and cleaner transport • Reducing pollution and greenhouse gas emissions

Anticipated battery degradation is among the main barriers to customer engagement in V2G programs and further research is required to better quantify this impact. The current understanding of the problem is addressed in detail in Section 4.2 of this report, where international literature has been reviewed. In general, V2X services that require only small changes in the battery’s state-of-charge (SOC) have relatively small degradation costs compared to services that require a large energy throughput.³⁰

An analysis of V2X annual value streams was conducted for a broad range of streams across multiple markets [add Thompson reference]. The assessment considered upper limits, lower limits and median annual value streams, to show that feeding into the grid at peak times to take advantage of TOU feed-in tariffs from a residential customer perspective was the most valuable stream, followed by the value in avoiding the need to upgrade network infrastructure (e.g. substations) by reducing peak demand within distribution networks. Further detail on value stream definitions and potential use cases is provided alongside annual value (\$/kW-year) in Table 3.

Table 3. V2X annual value streams meta-analysis shows the overall economic potential of key V2X value streams in terms of annual revenue (\$/kW-year), considering upper and lower limits and the median.²⁰ Adapted to include respective value stream definitions and potential use cases.

V2X Value Stream	Definition	Potential use cases	Annual Revenue (\$/kW-year)		
			Lower limit	Median	Upper limit
Bill Management	Strategic charging and V2X to manage exposure to residential tariffs	Residential customer value by discharging during peak TOU feed-in tariff, combined with avoidance of high peak charges	33	275	503
Network Deferral	Avoidance of investment in distribution network infrastructure	Reduction in peak demand avoiding the need for substation upgrades	28	110	276
Resource Adequacy	Ensuring enough generation capacity at the grid level to meet peak demand	V2X provides additional capacity at peak time, avoiding the need for expensive peaking plant	33	102	148

²⁰ Thompson, A.W., & Perez, Y. (2020). Vehicle-to-everything (V2X) energy services, value streams, and regulatory policy implications. *Energy Policy*, 137, 111136. <https://doi.org/10.1016/j.enpol.2019.111136>

Demand Response Utility	Markets provide incentives to reduce demand during peak times	Strategic charging and discharging can reduce overall demand on the network at peak times	52	95	220
Frequency Regulation	Markets incentivise 'fast response' generators to ameliorate frequency perturbations in the grid	Batteries can provide rapid response (sub-second) injection of power to help alleviate frequency perturbations	25	80	225
Demand Response Wholesale	Markets provide incentives to reduce demand during peak times	Strategic charging and discharging can reduce overall demand on the network at peak times	13	65	182
Reactive Power Support	Power Factor Correction (PFC), Reactive Power Control (RPC), and Voltage Regulation (VR) are normally provided by capacitor banks	EVSE can provide these services through providing/absorbing reactive power etc		55	
Site Renewable Energy Resource Firming	Battery backup used to smooth output from wind or solar farms	EV batteries can perform this task if the EV is situated in the proximity of the RE plant		50	
Energy Arbitrage	Taking advantage of the variability in the wholesale market prices (buy low, sell high)	EV batteries can discharge into the grid during high price events. Most residential customers however are not exposure to the wholesale market	0	24	87
Spinning Reserve	Wholesale markets require additional capacity to be available in the case of the failure of a generator or errors in forecast demand or RE output	EVs can provide additional capacity. Value in the market is limited	0	23	71

It was found due to the reduced degradation costs of V2X services requiring minimal changes in SOC, power-based (capacity) value streams, such as frequency regulation, which require less energy throughput, will be the most viable for V2X because they will not result in significant battery degradation. Resource adequacy and network deferral—where V2X would reduce future system peak loads—are other high revenue, power-based value streams. Network deferral, also known as non-wire alternatives³¹, via V2X would allow the grid to meet projected load growth and avoid or delay (for up to 2-3 years) the need to upgrade the distribution network³⁴ or individual substations. Figure 3 shows the annual value streams that V2X could service.

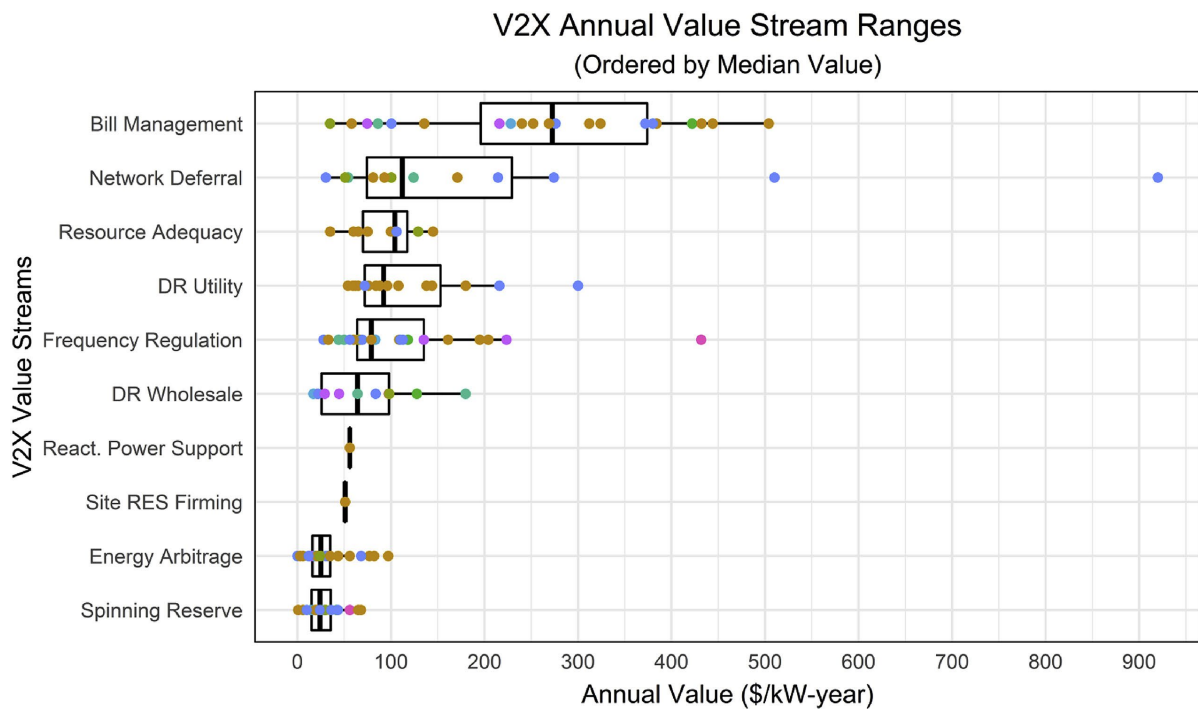


Figure 3: V2X annual value stream meta-analysis shows the overall economic potential of key V2X value streams in terms of annual revenue (\$/kW-year), considering upper and lower limits and the median.²¹

It is important to note that there are large variations in the economic potential of different value streams across different markets. This highlights the need for more research and modelling on the benefits of V2X in the Australian market.

2.2.1 V2G for EV owners

The integration of V2X services, including bulk V2G with holistic controlled-charging regimes, could deliver substantial energy and cost savings and at the same time prolong battery life.²² The benefit for EV owners depends on the tariff structure and battery degradation. The revenue that EV owners earn should compensate for battery degradation. Smart discharging strategies should also be applied to minimise battery degradation. Research results, reviewed in Section 3.2, confirm that an efficient, smart, bi-directional charging algorithm from a battery degradation perspective heavily depends on the daily routine of the EV and the ambient temperature, and thus requires local data-driven studies. One way around the congestion of the distribution network during peak periods would be to mandate ToU tariffs for households that wish to charge an EV. However, as the penetration of EVs increases, this has the potential to create a second peak. Therefore, encouraging EV owners to take advantage of real-time-based tariffs would be more effective. In a UK trial, such smart charging reduced the peak electricity consumption by up to 47%.²³

Research conducted in Melbourne focussed on the economic benefit of an EV combined with a home energy management system under various scenarios.²⁴ The study showed that implementing V2H reduced monthly

²¹ Thompson, A.W., & Perez, Y. (2020). Vehicle-to-everything (V2X) energy services, value streams, and regulatory policy implications. *Energy Policy*, 137, 111136. <https://doi.org/10.1016/j.enpol.2019.111136>

²² Ibid.

²³ Jones, L., Lucas-Healey, K., Sturmberg, B., Temby, H., & Islam, M. (2021). *The A to Z of V2G*. REVS/ANU. <https://apo.org.au/sites/default/files/resource-files/2021-02/apo-nid311127.pdf>

²⁴ Datta, U., Saiprasad, N., Kalam, A., Shi, J., & Zayegh, A. (2019). A price-regulated electric vehicle charge-discharge strategy for G2V, V2H, and V2G. *International Journal of Energy Research*, 43(2), 1032-1042. <https://doi.org/10.1002/er.4330>

electricity bills by 11.6% compared to unmanaged unidirectional charging. However, the study assumes that there are no additional costs to implementing bi-directional (V2H) charging and does not take battery degradation into account. Another study examined optimal algorithms to reduce the charging cost of EVs and proposes an innovative V2G algorithm called Optimal Logical Control.²⁵ However, the study only considers the French energy billing system and daily energy price profile and does not consider battery degradation.

2.2.2 V2G for grid operators

Optimised V2G technology can minimise the operational costs of an active distribution network with distributed energy resources.²⁶ It can also reduce energy costs by addressing solar energy intermittency and peak loading. Battery degradation can be minimised by operating V2G technology with a minimum charging-discharging cycle. Reducing the network operation costs using V2G is an opportunity for DNSPs to mitigate the cost of infrastructure upgrades for this technology. However, a long-term cost-benefit analysis is required to clarify the return on investment.

The inevitable trade-off between the costs and benefits of EV owners and DNSPs needs to be considered for a sustainable solution. A review of relevant literature shows that EV research on stakeholder costs and benefits frequently differ in methodology and approach, thus resulting in a range of different conclusions.

3 Regulatory and policy aspects of V2G

The following sections outline the regulatory landscape of Australia's energy market. While this report focuses on the NEM, regulations in separate markets such as those in Western Australia and the Northern Territory will also have to be explored in future research. We examine how the electricity market and network regulatory frameworks and laws interact with the integration of EVs into the grid, with a special focus on V2G. Electricity market interactions can take place with respect to wholesale and retail markets and networks. We also identify the key areas of interest for further exploration. Appendix II lists the regulatory framework surrounding the NEM and the market participants of the NEM.

3.1 Interaction of electric vehicles with the electricity grid and market

The interaction of EVs with the electricity system will happen at several points, impacting retailers, networks, and wholesale market outcomes and market participants. Large-scale EV adoption, as projected by AEMO, will not only significantly increase daily demand but, depending on the intra-day distribution of charging activities (assuming least-cost, tariff-based charging optimisation), influence prices and NEM infrastructure requirements. Intra-day charging and discharging patterns will be a key factor in determining what type of new generation (e.g. solar or batteries) will be required. As EVs gradually enter the market, this will put pressure on the system to incentivise the right type of generation investment that is well located to ease network congestion and contribute to a clean energy transition.

We expect that end-user tariffs will play a key role in the time of day when customers will charge their EVs. Using the current tariff system prevailing in Victoria and a least-cost economic charging method, Say et al. (2022) show that for public transportation most charging would take place at night, which is considerably more carbon intensive than daytime charging. The difference in the energy cost is due to extensive demand and network charges during the day. Customer tariffs can potentially mute wholesale market price signals, especially for large customers, and therefore the reaction to wholesale market signals will be very limited.²⁷ The Australian Energy

²⁵ Turker, H., & Bacha, S. (2018). Optimal minimization of plug-in electric vehicle charging cost with vehicle-to-home and vehicle-to-grid concepts. *IEEE Transactions on Vehicular Technology*, 67(11), 10281-10292. <https://doi.org/10.1109/TVT.2018.2867428>

²⁶ Mehrjerdi, H., & Rakhshani, E. (2019). Vehicle-to-grid technology for cost reduction and uncertainty management integrated with solar power. *Journal of Cleaner Production*, 229, 463-469. <https://doi.org/10.1016/j.jclepro.2019.05.023>

²⁷ Say, K., Csereklyei, S., Brown, F.G., & Wang, C. (2023). The Economics of Public Transport Electrification: A Case Study from Victoria, Australia. *Energy Economics* (in press). <https://doi.org/10.1016/j.eneco.2023.106599>

Regulator (AER) has recently ruled that households with an electric vehicle (with a Level 2 charger) must be offered a ToU tariff in Victoria and that flat rate tariffs will be prohibited.²⁸ Current ToU tariffs would also incentivise off-peak charging for EV owners.

Future regulation will have to focus predominantly on a tariff reform and how wholesale market signals could be better conveyed to end-users. It is imperative to develop the right economic incentives and regulatory requirements to incentivise EV owners to charge in a manner that is optimal for both system reliability and affordability. EV owners are likely to interact mostly with retailers (both when charging and discharging), and special focus should be directed to this area of regulation. In the next sections, we compile the key regulatory challenges and questions that will need to be addressed in the near future to enable the successful integration of EVs into the grid.

3.1.1 Wholesale market interactions

The first questions shaping the way EVs will interact with the electricity system relate to defining the purpose of the technology:

- What technology are we seeking to implement?
- Is the use of EVs as BESS (V2G activities included) feasible and desirable from a system and stakeholder point of view, or can we expect EVs to be largely consumers?
- Can EVs be effectively incentivised to participate in demand-side response (e.g., load shifting)?

EVs will be connected to the NEM from behind the meter. This means that, for the electricity system, they appear as either additional demand when charging, or as small-scale generators, similar to household rooftop PV, when discharging.²⁹ In theory, EVs could also provide demand-side management, responding to wholesale market signals asking them not to charge at times of tight supply or to charge when there is an abundance of renewable energy and minimum demand is falling fast. However, as noted earlier, current tariff structures can mute high frequency wholesale market signals.

In this regard, EVs act similarly to home batteries. Consumers with rooftop solar PVs can currently sell generation they do not use to their retailer or small generation aggregators, who, in exchange, provide a feed-in tariff. Demand response mechanisms for small consumers are currently not available as the AEMC considered in a recent rule change “*that the best approach is to develop a two-sided market, which is more suited to small customer involvement.*”³⁰ The two-sided market is part of the suite of reforms that the Energy Security Board (ESB) is undertaking post 2025.³¹ Depending on how the above-mentioned two-sided market is set up, the following legal questions will have to be asked:

- Can and should EVs interface with the electricity market other than as consumers?
 - To what degree does this interaction need to be facilitated and by whom (aggregator, retailer or DNSP)?

²⁸ Australian Energy Regulator. (2021, April). AER – Final Decision – AusNet Services Distribution Determination 2021–26: Attachment 19—Tariff Structure Statement. Australian Government. <https://www.aer.gov.au/system/files/Final%20Decision%20-%20AusNet%20Services%20distribution%20determination%202021%E2%80%9326%20-%20Revised%20Tariff%20Structure%20Statement%20-%20April%202021%20-%20Clean.pdf>re Statement - April 2021 - Clean.pdf (aer.gov.au)

²⁹ Discharging capability, while technically possible, is usually not provided as repeated charging and discharging of EVs negatively impacts battery lifespan. (See Brent, A. (2020, August 5). Could Electric Car Batteries Feed Power Back into the Grid?)

³⁰ Introducing demand response service providers for larger customers. (See AEMC. (2011, June 11). *Wholesale Demand Response Mechanism—Final Rule*). <https://www.aemc.gov.au/rule-changes/wholesale-demand-responsemechanism>

³¹ Energy Security Board. (2020, June 3). *Two-Sided Markets*. Department of Climate Change, Energy, the Environment and Water. <https://www.energy.gov.au/governmentpriorities/energy-ministers/energy-ministers-publications/two-sided-markets>

- What laws and regulations impact
 - Charging at an individual home?
 - Charging at a workplace (together with others)?
 - Charging in a strata building?
- By whom and how will EVs be regulated with respect to locational charging (i.e. whether and when they can draw electricity and feed it back into the grid)? For example, EVs could charge at work or when travelling and discharge at home, acting as a backup electricity supply.
- To what degree will AEMO be able to plan for, or constrain, these activities?

3.1.2 Grid planning and network-based interactions

EVs will interface with the distribution network rather than the transmission network. The distribution network is currently sized and designed for one-way flows, transporting electricity from substations (which interface between transmission and distribution networks) to end-consumers. In light of the projected EV uptake of the next decades, both transmission and retail networks have to be expanded and upgraded.³²

Depending on the rate of EV adoption, the following questions can directly clarify the impact of EV-grid interactions:

- What future grid design is best suited to accommodate EVs (from an intra-day load and locational demand point of view)?
- Which technical solutions—such as extended transmission network or neighbourhood/utility-scale BESS installation—are preferred? (Precursor non-legal question)
- How can legislation incentivise NSPs to build this type of grid, and how will revenue or tariff settings influence these choices?
- Is a change in roles and responsibilities of network providers required, or do new roles need to be created?

The regulatory framework for upgrading the distribution network has a 5-year planning horizon. Distribution networks are required to submit annual reviews of their expenditure and develop a demand-side engagement strategy. Whether, to what extent, and where electric vehicle uptake will lead to increased grid congestion (and required distribution grid upgrades) will depend on when and how EVs will connect to the grid. The AER has recently published a guidance note for DER Integration Expenditure that emphasises the use of tariff arrangements to “manage the demand for consumption and export services and make best use of existing network hosting capacity.”³³ Current policy documents by the federal government,³⁴ and the AEMO’s Integrated System Plan, treat EVs generally as added demand rather than potential supply, and although the potential of V2G is recognised, it is considered a future technology.

3.2 Current regulations and policies

The regulatory framework sets the background on how BESS can or cannot interact with the system, and with what part of the system they interact. The above section detailed the key legal questions that will have to be answered with respect to EV grid integration. In this section, we introduce the role of policies in EV uptake and integration, as well as the key policies and laws currently interacting with EV uptake in Australia.

³² Australian Energy Market Operator. (2022). *Integrated System Plan (ISP)*. AEMO. <https://aemo.com.au/-/media/files/major-publications/isp/2020/final-2020-integrated-system-plan.pdf?la=en>.

³³ Commonwealth of Australia. (2022). *DER Integration Expenditure Guidance Note*. <https://www.aer.gov.au/system/files/Final%20DER%20integration%20expenditure%20guidance%20note%20-%20June%202022.pdf>

³⁴ Australian Energy Regulator. (2021, November). *Future Fuels and Vehicles Strategy: Powering Choice*. Department of Industry, Science, Energy and Resources. Australian Government. <https://apo.org.au/sites/default/files/resource-files/2021-11/apo-nid315003.pdf>.

Say et al. (2022) note, based on IEA data,³⁵ that “the share of EVs from new sales across Europe and China in 2020 reached 10% and 5.7%, respectively, while Australia, at 1% of new car sales, remains far behind the global average of 4.6%.”³⁶ While EV uptake in Australia is in its starting phases, Say et al., based on Foley et al. (2020)³⁷, argue that “the higher costs of EVs, lack of charging infrastructure, range anxiety and low availability of EVs for purchase were affecting EV uptake in Australia.”³⁸ As observed in other countries, early adopters of EV passenger vehicles were typically of higher socio-economic status and had a greater degree of familiarity with the technology.³⁹

Governmental policies have often been identified as a key driver or barrier to technology diffusion, which is also true in the context of EVs.⁴⁰ Governments may set objectives, mandates and binding or non-binding targets as well as supporting policies (including monetary and non-monetary incentives).⁴¹ In their study examining the economics of public fleet electrification, Say et al. (2022) summarise the key insights from past literature, noting that:

- Subsidies on upfront costs were preferred over rebates on operating costs.⁴²
- Financial incentives are a major factor influencing EV adoption and may yield up to a 5-7% increase in relative sales share per €1000.^{42,43}
- Strong vehicle emissions standards, combined with the correct institutional settings, are a critical factor in EV uptake.⁴⁴
- In the absence of Australian federal policy, state governments have introduced state-based EV strategies, which predominantly focus on upfront subsidies and are not coordinated across jurisdictions.

One of the main contributions of this report is a comprehensive collection of Australian federal and state regulations and policies relevant to EV uptake and the EV-grid interaction. **Appendices II and III** list these regulations and policies and can serve as a major resource for future research.

3.3 Other regulatory considerations

Other key areas of regulation relevant to EV integration include residential building codes and standards.

3.3.1 Interactions with residential buildings and building law

The rate of service electrification in Australian residential properties is expected to increase through changes such as increased uptake of EVs and installation of electric appliances, e.g. heat pumps and electric hot water systems. Particularly owners of PV solar panels and BESS can be expected to become early adopters of EVs. Solar rooftop generation in the past years has resulted in lowered operational minimum demand during the day. EV charging

³⁵ International Energy Agency. (2021). *Global EV Outlook 2021*. IEA. <https://www.iea.org/reports/global-ev-outlook-2021>.

³⁶ Say, K., Csereklyei, S., Brown, F.G., & Wang, C. (2023). The Economics of Public Transport Electrification: A Case Study from Victoria, Australia. *Energy Economics (in press)*, 106599. <https://doi.org/10.1016/j.eneco.2023.106599>

³⁷ Foley, B., Degirmenci, K., & Yigitcanlar, T. (2020). Factors Affecting Electric Vehicle Uptake: Insights from a Descriptive Analysis in Australia. *Urban Science*, 2020, 4(4), 57. <https://doi.org/10.3390/urbansci4040057>

³⁸ Ibid

³⁹ Brückmann, G., Willibald, F., & Blanco, V. (2021). Battery Electric Vehicle Adoption in Regions without Strong Policies. *Transportation Research Part D: Transport and Environment*. <https://doi.org/10.3929/ethz-b-000460728>

⁴⁰ Azarafshar, R., & Vermeulen, W. N. (2020). Electric vehicle incentive policies in Canadian provinces. *Energy Economics*, 91. <https://doi.org/10.1016/j.eneco.2020.104902>

⁴¹ Say, K., Csereklyei, S., Brown, F.G., & Wang, C. (2023). The Economics of Public Transport Electrification: A Case Study from Victoria, Australia. *Energy Economics (in press)*, 106599. <https://doi.org/10.1016/j.eneco.2023.106599>

⁴² Münzel, C., Plötz, P., Sprei, F., & Gnann, T. (2019). How large is the effect of financial incentives on electric vehicle sales? A global review and European analysis. *Energy Economics*, 84, 104493. <https://doi.org/10.1016/j.eneco.2019.104493>

⁴³ Azarafshar, R., & Vermeulen, W. N. (2020). Electric vehicle incentive policies in Canadian provinces. *Energy Economics*, 91, 104902. <https://doi.org/10.1016/j.eneco.2020.104902>

⁴⁴ Kohn, E., Huang, C., Kong, N., & Hardman, S. (2022). *Electric Vehicle Incentives in 15 Leading Electric Vehicle Markets*. Institute for Transportation Studies, University of California, Davis. <https://econpapers.repec.org/RePEc:cdi:itsdav:qtotn2p4x6>

appears as an additional load for owners and residents.⁴⁵ Depending on how ‘smart’ the building technology is, EV batteries may in time become an extension of the home system and may be utilised for personal or grid purposes. Currently, an EV battery is primarily a standalone energy supply that provides traction to move the vehicle.

With increased adoption, EV-charging infrastructure development will be required at home⁴⁶, at work and on the road⁴⁷, enabling safe charging.⁴⁸ Not all households own vehicles or have a car space⁴⁹; this might particularly be the case for the three million Australians living in multi-unit residential buildings.⁵⁰

Buildings: The residential property sector plays a key role in the uptake of EVs because different housing stock gives owners different permissions to alter the property. Standalone buildings enable the owners to make personal decisions on what and when they invest in the property. Homeownership, in particular, allows for the instalment of solar rooftop panels or batteries, or refurbishments, to accommodate EVs. Subdivided buildings are subject to more restrictions due to the joint ownership of the common property. Occupants may be commercial businesses and residents, or the property may be purely residential. The residents may be owner occupiers or tenants. An alteration to any part of the property may impact directly all other individual owners and residents or the building as a whole.

The majority of Australia’s population lives in major metropolitan centres. In response to population growth, inner city councils have increasingly permitted higher density, multi-unit (strata) properties to be constructed in locations where they were previously limited for height reasons. These multi-unit properties tend to be better connected to a range of public transport services. The majority of this strata building stock will require energy efficiency refurbishments in the future, and charging points for EVs will have to be established. It will likely be difficult for strata building owners to easily alter their premises to accommodate this rising need.

As an example, in Victoria the *Owners Corporation Act 2006*⁵¹ governs how strata properties are managed and is the basis for the decision-making process of an owner’s corporation when contemplating the enablement of V2X solutions. The policies and legislation in each state and territory governing owners corporations should be reviewed to enable a safe and sustainable EV uptake. Appendix III of this report provides a comprehensive law and regulation table in the Victorian legislation.

The *Residential Tenancies Act 1997 (Vic)*⁵² provides the framework within which landlords and tenants operate. Recent updates to the *Act* have aimed to provide better protection for tenants and to lift landlord rental property standards (e.g. Victorian landlords now have an obligation to provide heating). However, both the tenants’ and landlords’ duties and obligations become more complex when the residence in question is part of an owners corporation.

⁴⁵ Australian Energy Market Operator. (2021). Distributed Energy Integration Program – Electric Vehicles Grid Integration: Vehicle-Grid Integration Standards Taskforce – Key Findings. AEMO. https://aemo.com.au/media/files/stakeholder_consultation/working_groups/der-program/deip-ev/2021/deip-vgi-standardsreport.pdf?la=en.

⁴⁶ Datta, U., Saiprasad, N., Kalam, A., Shi, J., & Zayegh, A. (2019). A price-regulated electric vehicle charge-discharge strategy for G2V, V2H, and V2G. *International Journal of Energy Research*, 43(2), 1032-1042. <https://doi.org/10.1002/er.4330>

⁴⁷ Graham, P., & Havas, L. (2021). Electric Vehicle Projections 2021. CSIRO, Australia. https://aemo.com.au/-/media/files/electricity/nem/planning_and_forecasting/inputs-assumptionsmethodologies/2021/csiro-ev-forecast-report.pdf

⁴⁸ Panasiewicz, C. K. (2015, December 16). Electric vehicles and the unique risks insurers need to consider. *Origin and Cause: Electrical Engineering*. <https://origin-and-cause.com/experts/chris-k-panasiewicz/>

⁴⁹ Graham, P., & Havas, L. (2021). Electric Vehicle Projections 2021. CSIRO, Australia. https://aemo.com.au/-/media/files/electricity/nem/planning_and_forecasting/inputs-assumptionsmethodologies/2021/csiro-ev-forecast-report.pdf.

⁵⁰ Easthope, H., Buckle, C., & Mann, V. (2018) Australian National Strata Data 2018. City Futures Research Centre, UNSW, Australia. <https://apo.org.au/sites/default/files/resource-files/2018-05/apo-nid174131.pdf>

⁵¹ *Owners Corporations Act 2006 (Vic)*. <https://www.legislation.vic.gov.au/in-force/acts/owners-corporations-act-2006/017>

⁵² *Residential Tenancies Act 1997 (Vic)*. <https://www.legislation.vic.gov.au/in-force/acts/residential-tenancies-act-1997/090>

Altering existing strata building stock to enable V2X interactions is defined as a major project⁵³ for an owners corporation. Technically, this presents a significant upgrade, and one that would have to be conducted in an occupied strata property, requiring all lot owners to engage with major project works that can be financially untenable for some. Recent evacuations of high-rise buildings have also highlighted quality and standards issues (e.g. structural faults—Opal Towers, Mascot Towers and others, and combustible cladding—Southern Cross Building), plaguing the residential construction sector and doing little to build consumer confidence.

Key areas of future EV-building interaction research are recommended to include –

- a review of state planning and building regulations to identify potential planning or building requirements/implications for the installation and operation of hybrid V2H infrastructure and public hybrid V2G stations
- a review of various industry standards of small-scale battery storage installation and operation (e.g. Energy Safe Victoria’s guidance on the installation of grid-connected PV systems)

It will also be important to explore whether standards appear to place any distinct restriction on grid-connected, small-scale battery storage.

3.3.2 Standards

Regulation of electric car battery and charging infrastructure standards. The regulation of both car batteries and charging infrastructure is paramount, especially from the viewpoint of fire safety. Standards Australia has undertaken an extensive consultation process to create the standard *AS/NZ 5139 2019 Electrical installations—Safety of battery systems for use with power conversion equipment*. While this standard covers fixed batteries in properties, EV batteries are not specifically included. For this standard to be mandatory for vehicles, it either has to be referenced in the Australian Wiring Standards (AS3000) or in state legislation.

3.3.3 Equitable access to sustainability items

Technical and socio-economic considerations are needed to assess how equitable access to clean energy supply can be provided to all Australians. For example, people might be disadvantaged in the uptake of new technologies because they are renters and not homeowners where the style of residence inhibits the installation of sustainability measures. Therefore, uptake of EVs will likely involve community-based infrastructure provision and, in time, the replacement of petrol stations with similar commercial charging stations.

⁵³ *Domestic Building Contracts Act 1995* (Vic). <https://www.legislation.vic.gov.au/in-force/acts/domestic-building-contracts-act-1995/086>

4 Technical challenges and standards

V2G-enabled EVs can support the grid by providing frequency/voltage services, support for intermittent power of solar/wind power, reactive power support, load balancing, valley filling and peak shaving. In order for V2G to be used for ancillary services, we need to have a sufficient number of V2G-enabled vehicles connected to the grid at the same time. This can be the case for airport or shopping centre parking spaces with EV chargers⁵⁴, making these locations the first candidates for V2G trials. To make V2G technology useful, the vehicle battery also has to have sufficient energy capacity for daily travel needs and to inject any remaining energy into the grid.

4.1 V2G implementation

Implementation architecture for bi-directional charging (i.e., when EVs can also be discharged to support the grid) is the first challenge in enabling V2G in a power grid. Suppose a V2G-enabled EV owner decides to participate in the FCAS market. The charger/owner should be able to receive market signals such as electricity cost and put a bid in the market. This is currently the case in the FCAS market for generation units connected to the transmission grid. However, extending this solution to the distribution grid is challenging. The bi-directional charging infrastructure may require a new entity, such as a charging station master or aggregator, to manage the communication between EVs, DNSP and the market. The architecture, the role of each entity, and the interactions between them need to be well regulated. Among different strategies for implementing V2G, aggregators have attracted a lot of attention in the literature.

4.1.1 Aggregation strategy

V2G is primarily composed of bi-directional charging stations and EVs, along with communication and charging facilities. Charging stations (CS) are deployed to monitor each EV/V2G charger and group them together such that, when aggregated, they have sufficient energy capacity to have a meaningful impact on the grid. Usually, at least a few hundred EVs need to be aggregated to provide/absorb MWh-level electrical energy to and from the power grid.⁵⁵ To put this further into context, 1 MWh of energy storage would be provided by 25 Nissan Leaf cars with 40 kWh battery capacity each.

Aggregators have an important role in making it possible for V2G-enabled EVs to provide services. Figure 4 shows a sample framework for implementing an aggregator for frequency and voltage support services. The aggregator requires bi-directional communication with the market, EVs, DNSP and the transmission service provider. Once information, including market price and the reference regulation imposed by the grid operator, has been provided, the aggregator decides on a set of EV charging/discharging control commands. The main objective is to minimise the EV charging price and provide ancillary services to the market. The market price regulation, and the reference regulation imposed by the grid operator, are the variables by which the decisions are made. Aggregators need to apply smart algorithms such as the day-ahead market to assure the profit of EVs and reduce the battery degradation cost.⁵⁶ Finally, the aggregator distributes the revenue to vehicle owners that have been connected to that aggregator during the V2G operation.

Despite this important role, a standard framework for the aggregators and their relationship with other parties, such as DNSPs, is still lacking. Currently, smart meter data are collected and recorded by DNSPs. However, considering the role of aggregators in implementing V2G services (Fig. 3), the data collection, storage and sharing policies for all possible contributors, including public charging stations, should be revisited. In addition, the

⁵⁴ Dubey, A., & Santoso, S. J. I. A. (2015). Electric vehicle charging on residential distribution systems: Impacts and mitigations. *IEEE Access*, 3, 1871-1893. <https://doi.org/10.1109/ACCESS.2015.2476996>

⁵⁵ Ravi, S. S., & Aziz, M. (2022). Utilization of Electric Vehicles for Vehicle-to-Grid Services: Progress and Perspectives. *Energies*, 15(2), 589. <https://doi.org/10.3390/en15020589>

⁵⁶ Vatandoust, B., Ahmadian, A., Golkar, M. A., Elkamel, A., Almansoori, A., & Ghaljehei, M. (2018). Risk-averse optimal bidding of electric vehicles and energy storage aggregator in day-ahead frequency regulation market. *IEEE Transactions on Power Systems*, 34(3), 2036-2047. [doi:10.1109/tpwrs.2018.2888942](https://doi.org/10.1109/tpwrs.2018.2888942)

challenge of how DNSPs can maintain their visibility and control of the distribution grid in the presence of aggregators needs to be carefully addressed.

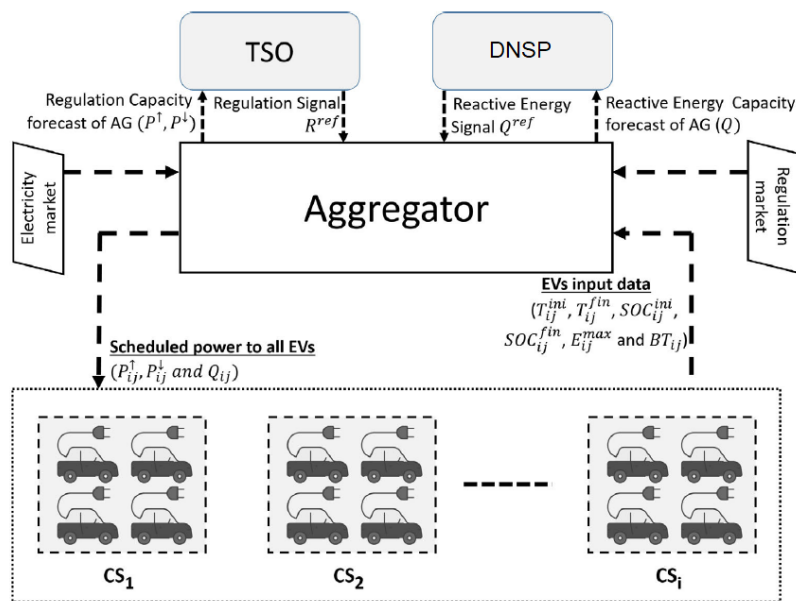


Figure 4. Aggregator framework as an interface between EV fleet and grid operator⁵⁷

4.2 Degradation of EV battery lifetime

Original equipment manufacturers (OEMs) and EV owners may not be willing to engage in V2G schemes due to the possibility of increased battery degradation. Conversely, smart-charging algorithms that can maximise battery life may reduce flexibility for the provision of grid services, and so an important task for aggregators/operators is to identify the optimal operational settings. The main concerns about a battery's state of health (SoH) relate to calendar ageing and cycling ageing, which can happen through a reduction of total capacity and/or an increase in internal impedance. The most common factors that contribute to battery degradation are temperature, charging/discharging rates, state of charge (SoC) and depth of discharge (DoD) levels.⁵⁸ When the battery is used for frequency regulation services, increasing the ambient temperature can significantly reduce the battery life. M. Schimpe and colleagues found that both high and low temperatures will lead to high-capacity loss, with the optimum temperature for battery health being 25°C.⁵⁹

The literature shows several contradictory results about the impact of V2G on battery degradation. For example, it has been shown that, even while employed for V2G charging, calendar ageing is still the dominant life-reducing factor for vehicle batteries. Another experimental study demonstrated that additional cycling to discharge vehicle batteries (as is the case with V2G) is detrimental to battery performance, even if the discharge rate is kept constant. In contrast, a model-based study considering a comprehensive model of an EV powertrain, shows that frequency regulation and peak load shaving do not cause significant degradation of EV batteries even if they are carried out daily. Some research articles have shown that pure modelling approaches cannot precisely predict

⁵⁷ Amamra, S., & Marco, J. (2019). Vehicle-to-Grid aggregator to support power grid and reduce electric vehicle charging cost. *IEEE Access*. <https://doi.org/10.1109/ACCESS.2019.2958664>

⁵⁸ Schimpe, M., von Kuepach, M. E., Naumann, M., Hesse, H. C., Smith, K. & Jossen, A. (2018). Comprehensive modeling of temperature-dependent degradation mechanisms in lithium iron phosphate batteries. *Journal of The Electrochemical Society*, 165(2), 181. <https://doi.org/10.1149/o8010.0147ecst>

⁵⁹ Ibid

battery degradation due to V2G and that more experimental studies are required in different operational conditions. Some research articles even claim that V2G can extend the EV battery life. For example, simulation results show that discharging up to 40% of the state of charge of the battery to the grid can reduce capacity fade by approximately 6% for normal cars with a daily drive cycle between 21% and 38% SoC.

Australia still suffers from a lack of research on modelling the SoH of EV batteries. This modelling is crucial for different sections of the EV market, such as the second-hand market and insurance companies. EV owners are also expressing concerns about the operation of aggregators and how V2G impacts the SoH of their batteries. An inherent feature of smart charging is the transfer of control from the EV owner to the orchestration engine (typically the aggregator). Thus, developing and implementing smart charging mechanisms are crucial for customer engagement in V2G programs.

4.2.1 Smart bi-directional charging

In general, aggregators can manage the charging/discharging of EVs in a centralised or decentralised control structure, or a hierarchical architecture including multi-layer interaction algorithms. Technically, the easiest scheme is the centralised scheme. In this scheme, the aggregator gathers the information and charging requirements about each vehicle, determines the EVs' charging/discharging rate based on the network conditions and considering specific objectives, such as maximising EV owner's benefit or frequency control, and finally sends a command to the chargers to optimise the process. In this scheme, EV owners delegate the charging/discharging responsibility to the aggregator. That means the aggregator can freely decide on the charging/discharging rate and time of the EV, normally based on the previous agreement with owners. This centralised option has several limitations. One limitation is that, if the aggregator optimisation system collapses, the whole system is affected. Another is its lack of scalability; increasing the number of EVs will result in a larger computational burden, especially in real-time action cases, making optimisation more difficult.

The second scheme, decentralised control method, allows each EV owner to control the charging process depending on their requirements. With the help of strategies such as price incentives, system operators and aggregators may indirectly adjust the behaviour of EVs. The decentralised scheme does not permit direct control by aggregators; thus, achieving the optimal solution is not guaranteed, and offering ancillary services is more challenging. However, this approach is highly scalable and suitable for large-scale EV fleets as it distributes the computational burden across all EVs, ensuring that each vehicle addresses its own charge and discharge tasks.

Smart V2G provides an even stronger potential for demand response to further reduce the peak load and increase asset utilisation of the network (i.e. relieve the network congestion and reduce network upgrade necessity). However, customer engagement in V2G programs depends on how the smartness of these algorithms guarantees benefits to EV owners to offset the cost of battery degradation. For example, aggregators can limit the discharge time of the battery for V2G based on an agreement with the EV owner. Octopus, as part of their Powerloop product, also provides an app for customers to enter their schedule and offer cash back only if customers complete a minimum number of V2G sessions per month. The app also gives customers the option to override V2G, and the agreement guarantees a minimum battery state of charge of 30%.⁵⁹ The override option is particularly important as it gives EV owners the feeling of full control should they need it. However, the app-based model comes with the assumption of a single user rather than a car shared between members of a household. Some chargers overcome this issue. For example, the Indra V2G charger used as part of Ovo Energy's program includes a boost mode that can be activated either via the app or directly by using the charger's boost button.⁶⁰

REVOLVE (Fig. 5) is the foresight optimisation model that has been used in the Scirus trial and is capable of simulating the charging/discharging behaviour of large numbers of EVs at half-hourly granularity over a year. The model optimises the charging/discharging behaviour of individual EVs on a minimum cost basis using the import

⁵⁹ Octopus Energy. Powerloop – Vehicle to grid technology. <https://www.octopusenergy.com/powerloop>

⁶⁰ Ovo Energy. Your vehicle-to-grid charger. <https://www.cenex.co.uk/app/uploads/2021/03/Merged-Slides-OVO-Indra-Nissan.pdf>

and export tariffs available. It covers an entire year by optimising weekly blocks one at a time. Although algorithms and programs to deal with the owner’s requirements are mainly retail or distribution concerns, the structure of the system to let V2G provide services to the transmission grid (i.e. interconnection of EV owners, DNSPs, aggregators and AEMO) should be regulated.

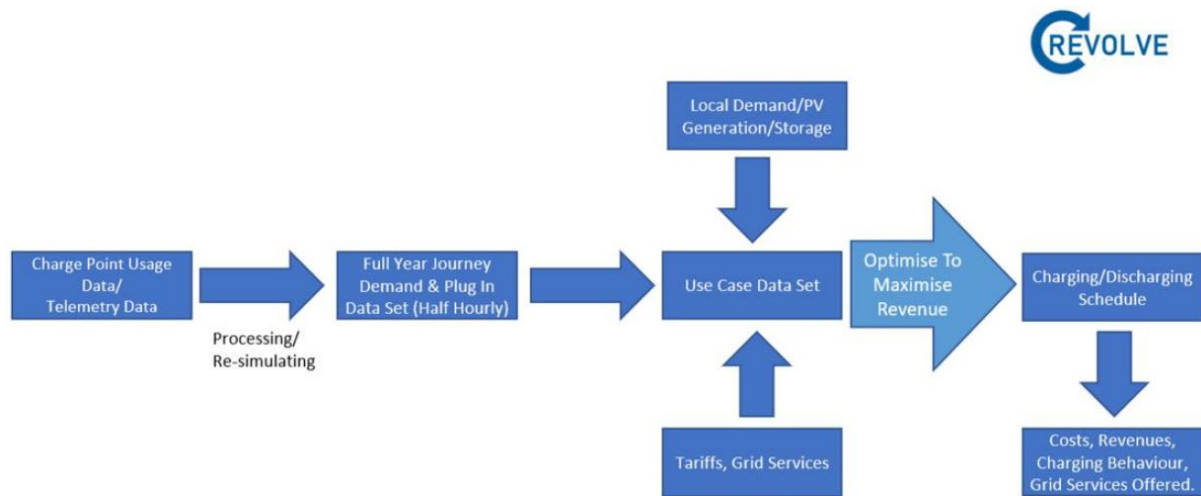


Figure 5. Cenex REVOLVE model diagram.⁶¹

4.3 Energy losses and infrastructure upgrade

Supporting mass number of EVs on our roads will incur significant costs in electricity infrastructure upgrades. In the UK, a projected 8GW of additional EV load is expected to increase peak demand to as high as 85GW by 2050, but this additional load can be reduced to 3.5 GW using smart charging.⁶² Even at 3.5 GW, however, EV penetration into the grid may overload distribution grid transformation and thereby increase energy losses.

However, it is important to distinguish between uncontrolled charging, smart charging and bi-directional charging of EVs (such as V2G). V2G will increase both the energy transfer on the grid and the energy losses, reducing the effective life of the grid infrastructure. For example, the life decrease of a distribution transformer in the case of uncontrolled EV charging is significantly greater than when charging is controlled.⁶³ In other words, while the demands of EVs will eventually necessitate upgrades of electricity infrastructure, a V2G scheme could substantially mitigate these new electricity infrastructure costs. International electricity distributors, such as distributors in California⁶⁴, have already started to implement a ‘non-wire alternatives’ concept in the distribution grid. The predominant objective is to smartly manage energy generation and storage capacity in active distribution grids in order to minimise infrastructure upgrades. V2G can contribute to implementing this concept alongside BESS and solar generation. In addition to the infrastructure upgrade cost saving, V2G can also support the grid by providing FCAS, power during peak demand periods, and by enabling higher penetrations of renewable electricity. The

⁶¹ Cenex. (2019). Understanding the True Value of V2G Report. https://www.ev-elocity.com/news/cenex-release-understanding-the-true-value-of-v2g-report/#:~:text=Source%3A%20Cenex%2C%20%2E2%80%9CUnderstanding%20the%20True%20Value%20of%20V2G%2C%2E2%80%9D_Service%3B%20Distribution%20System%20Services%3B%20and%20Wholesale%20Energy%20Market.

⁶² National Grid ESO. (2017). Future Energy Scenarios. <https://www.nationalgrideso.com/future-energy/future-energy-scenarios>

⁶³ Moghe, R., Kreikebaum, F., Hernandez, J. E., Kandula, R. P., & Divan, D. (2011). Mitigating distribution transformer lifetime degradation caused by grid-enabled vehicle (GEV) charging. 2011 IEEE Energy Conversion Congress and Exposition: *IEEE*, pp. 835-842. <https://doi.org/10.1109/ECCE.2011.6063857>

⁶⁴ Frick, N.M., Price, S., Schwartz, L.C., Hanus, N.L., & Shapiro, B. (2021). Locational Value of Distributed Energy Resources. Lawrence Berkeley National Laboratory. <http://dx.doi.org/10.13140/RG.2.2.30236.00642>

benefits include lower energy and transport costs, and increased potential for energy self-sufficiency. There is also potential for reducing pollution and greenhouse gas emissions.

4.4 V2G services for grid support

The availability of EVs for V2G services can produce energy savings, efficient supply management, and alternating renewable energy storage utilisation. V2G services will benefit both distributors and +EV users in mitigating grid congestion, as well as motivating EV users to benefit financially by making their vehicle available for V2G services.

4.4.1 Active/reactive power regulation

One of the most efficacious of the V2G services is the exchange of active power for load levelling purposes. As EV charging is more likely during peak hours, V2G scheduling can assist to prevent peak loading issues. Different optimisation procedures are applied—potentially by aggregators—in order to design an optimal V2G schedule. These schedules consider the EVs’ arrival and departure times and their arrival state-of-charge, along with the energy contribution of EVs equipped with V2G technology. A reliable prediction of potential V2G contribution requires the prediction of the EVs arrival time as well as its discharge capacity, which can be obtained by comprehensive data analysis using advanced machine learning techniques (see sample algorithm in Fig. 5).

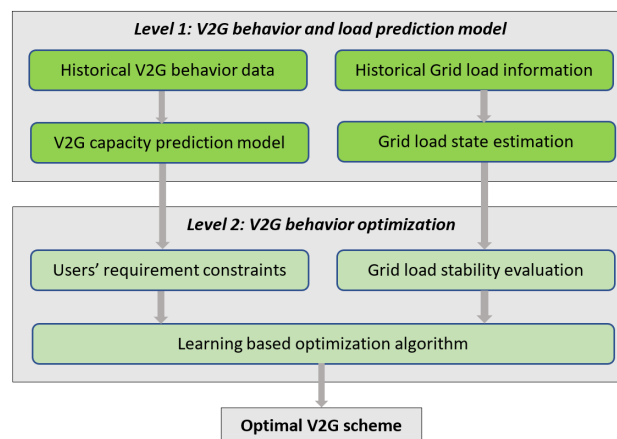


Figure 6. A V2G capacity prediction model⁶⁵

4.4.2 Frequency control ancillary service

Energy storage systems have the potential to compensate for frequency deviations promptly and precisely. Traditionally, this service is provided by conventional generators for free, but with the increasing withdrawal of coal-based generation, it will need to be provided by other sources. Regulating the frequency has become increasingly complicated because of the decrease in system inertia and increased volatility resulting from the growing share of renewable energy sources. V2G-enabled EVs can contribute to the FCAS market through the aggregation of EV behaviour.⁶⁶ In addition to increasing the visibility and controllability of AEMO over the distribution grid, providing this service requires appropriate response time (in the case of fast response services) as well as a policy that will protect owners’ benefits while providing reliable services to the grid.

⁶⁵ Adapted from Li, S., Gu, C., Li, J., Wang, H. & Yang, Q. (2020). Boosting grid efficiency and resiliency by releasing V2G potentiality through a novel rolling prediction-decision framework and deep-LSTM algorithm. *IEEE Systems Journal*, 15(2), 562-2570. <https://doi.org/10.1109/JSYST.2020.3001630>

⁶⁶The Manufacturer. (2020, June 12). Indra announces plans for the world’s largest technology trial. <https://www.themanufacturer.com/articles/indra-announces-plans-for-the-worlds-largest-v2h-technology-trial>

Droop control is a conventional local frequency control technique implemented in generation units that modifies the injected active power in a manner that is linearly proportional to the variation of frequency. The same control strategy can be applied to energy storage systems. Droop control, combined with a dead band to reduce battery degradation, can be used as the primary frequency control service. As it requires fast response inverters, appropriate standards settings should be considered. The dead band, and the slopes of the droops, must be determined based on the characteristics of the system, the owner's willingness to assist in frequency regulation, and the battery features. All of these items require significant laboratory studies before going to trial. Secondary frequency control can also be provided by sending a setpoint from the operator to the aggregator (or DNSP). To participate in this market, the aggregator needs to have sufficient V2G reserve. Aggregators can place their bids in the market based on forecasts of EV charging patterns, predicted V2G capacity, and contractual agreements with the EVs. These contracts will allocate a minimum number of hours—daily or monthly—to the EVs for secondary reserves. They may also define the control ranges for each EV, for instance, the possibility of entering V2G mode or working only as controllable loads. For EV owners, participation in the related market is highly advantageous as they leave their vehicles parked for most of the day and can put their vehicles 'to work' during this time.

4.4.3 EV for operating reserves

Operating reserves are capacity-based services that are dispatched as needed. The spinning reserve resource must achieve full generation level within a limited time after receiving the dispatch signal. V2G-enabled EVs can either provide operating-positive reserves by exporting extra power to the grid, or negative reserves by adding further load to the system.⁶⁷ The mobile nature of EVs may help to support remote communities in cases of emergency or lack of generation, preventing the need to expand the grid. For example, a V2G-enabled school E-bus, which is parked in a regional area most of the time, could be considered as a local operating reserve.

4.4.4 Supporting renewables

The maximum benefit of V2G/V2H/V2L is achieved if EVs are charged using clean renewable energy. This encourages owners to charge their EVs through the rooftop solar panels of households in distribution grids, or through daily charging using electricity that is mainly generated by solar or wind farms. By predicting the supply and using the flexibility of bi-directional EV charging, network operators can mitigate minimum energy demand challenges, increase network and renewables utilisation, and provide flexibility for using energy stored in EV batteries via V2G or V2H opportunities. This requires network operators to put in place comprehensive energy storage management system, including flexible loads and (battery) energy storage systems as well as EVs. There is also a need to develop strategies which can orchestrate V2G with existing DERs in low-voltage networks to capture associated opportunities and avoid risks.

4.5 EV-related standards and grid codes

Standardising every aspect of EV-integrated infrastructure is essential for its efficient operation. There are five distinct areas within which EV charging can be standardised: EV charging components, data and communication infrastructures, grid integration, safety, and trading in energy/services markets (e.g. retail). Figure 7 shows some internationally used standards in the context of integrating EVs into the electricity grid.

⁶⁷ Gschwendtner, C., Sinsel, S. R., & Stephan, A. (2021). Vehicle-to-X (V2X) implementation: An overview of predominate trial configurations and technical, social and regulatory challenges. *Renewable and Sustainable Energy Reviews*, 145, 110977. <https://doi.org/10.1016/J.RSER.2021.110977>

Simply Connecting

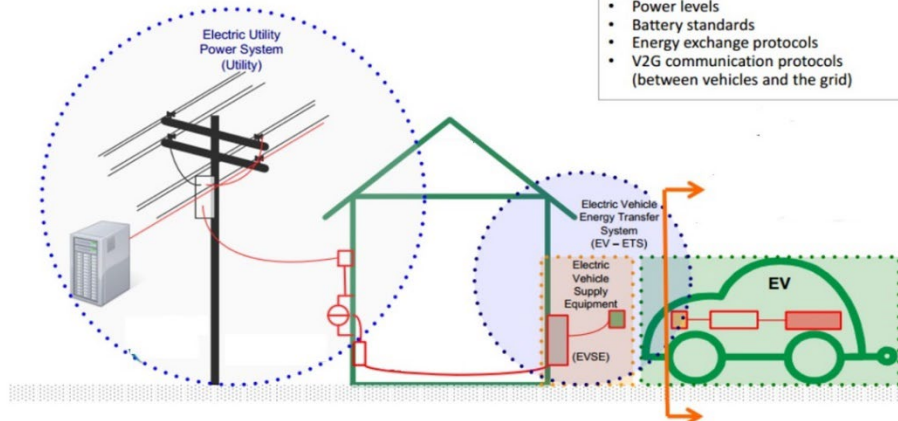


Figure 7. Different EV charging standards and their application areas⁶⁸

Integrating V2G technology will require the standardisation of hardware, safety requirements and communication protocols. Compatibility and interoperability among EV-specific components and grid systems can be categorised into four different sets of standards: (1) plug, (2) communication, (3) charging and (4) safety.

Plug

- IEC 62196-1: Plugs, socket-outlets, vehicle connectors and vehicle inlets—General requirements for conductive charging of electric vehicles
- IEC 62196-2: Plugs, socket-outlets, vehicle connectors and vehicle inlets—Dimensional compatibility and interchangeability requirements for AC pin and contact-tube accessories
- IEC 62196-3: Plugs, socket-outlets, vehicle connectors and vehicle inlets—Dimensional compatibility and interchangeability requirements for DC and AC/DC pin and contact-tube vehicle couplers

Communication

- ISO 15118-20 (2022): Vehicle-to-grid communication interface
- IEC 61850: Communication protocols for electrical substation systems and networks

Charging

- IEC 61851-1: Electrical vehicle conductive charging system—General requirements for different charging modes
- IEC 61851-21: Electrical vehicle conductive charging system—Requirements for conductive connection to AC/DC supply for both on-board and off-board charging systems
- IEC 61851-22: Electrical vehicle conductive charging system—AC charging station
- IEC 61851-23: Electrical vehicle conductive charging system—DC charging station
- UL 9741: Standard for bi-directional electric vehicle charging system equipment

Safety

- IEC 61140: Protection against electric shock—Common aspects for installation and equipment
- IEC 62040: Uninterruptible power systems (UPS)
- IEC 60529: Classification and ratings for degrees of protection provided by enclosures

⁶⁸ Das, H. S., Rahman, M. M., Li, S., & Tan, C. W. (2020). Electric vehicles standards, charging infrastructure, and impact on grid integration: A technological review. *Renewable and Sustainable Energy Reviews*, 120, 109618. <https://doi.org/10.1016/j.rser.2019.109618>

4.5.1 EV charging system

Regarding EV-charging infrastructure, several international standards are available that vary from country to country. In the US, SAE⁶⁹ and IEEE⁷⁰ standards are widely used, whereas in Europe, IEC⁷¹ standards are dominant. Japan has its own EV-charging standard, known as CHAdeMO. For AC and DC charging, China follows Guobiao (GB/T) standards, in which GB/T AC charging standards are similar to IEC specifications.

There is a significant difference in the design of ports and connectors among these charging standards. In the US, SAE J1772 connectors are used and provide AC and DC charging capabilities. Tesla has developed its fast-charging connector, which is compatible with AC and DC. The ‘combo’ connector is another popular charging connector found in Europe. To produce this combo, separate DC charging pins are added to the existing AC-charging connectors. In recent years increased efforts have been made to develop a universal solution and harmonise the charging standards between different manufacturers, but this work is still ongoing.⁷²

By establishing EV-charging standards in Australia, manufacturers and providers of EV infrastructure would be able to make efficient investments in future EV-related product launches with less risk. Legislating proper standards and regulations for charging systems will enable car manufacturers to import EVs with standard plugs, allow infrastructure providers to deploy standard charging stations, and accordingly support consumers to access adequate charging stations. In this regard, Australia’s vehicle industry has committed to harmonising national EV-charging standards to promote the uptake of EVs and the deployment of public charging infrastructures. Members of the Federal Chamber of Automotive Industries (FCAI) have agreed to provide vehicles and electric vehicle supply equipment (EVSE) capable of operating with charging infrastructure that is compliant with IEC 61851-1, IEC 62196-2 and IEC 62196-3 from 2020.⁷³

The regulation of both car batteries and charging infrastructure is paramount, especially from the viewpoint of fire safety. Standards Australia has undertaken an extensive consultation process to create the standard AS/NZ 5139 2019 *Electrical installations—Safety of battery systems for use with power conversion equipment*. While this standard covers fixed batteries in properties, EV batteries are not specifically included. For this standard to be mandatory for vehicles, it either has to be referenced in the Australian Wiring Standards (AS3000) or referenced in state legislation.

4.5.2 Data and communication infrastructures

As already shown in Figure 4, the implementation of V2G requires effective communication infrastructure between EVs, aggregators, DNSPs and the network operator. To begin with, EV owners send a request and related settings to the aggregator to show interest in participating in the market (using V2G). The aggregators then run an optimisation problem that considers technical and economic aspects in collaboration with DNSPs and the network operator. Finally, the aggregator updates the setting of the EV charger to respond to the EV owner’s request. This process is continuously repeated in response to the market. Effective communication infrastructure also requires that the details of the information shared among the participants are determined and the operational limits and technical requirements for implementing effective control by certain standards are identified.⁷⁴

⁶⁹ Society of Automotive Engineers. <https://www.sae.org/standards/>

⁷⁰ Institute of Electrical and Electronics Engineers Standards Association. <https://standards.ieee.org/>

⁷¹ International Electrotechnical Commission. <https://www.iec.ch/standards-development>

⁷² Habib, S., Kamran, M., & Rashid, U. (2015). Impact analysis of vehicle-to-grid technology and charging strategies of electric vehicles on distribution networks—a review. *Journal of Power Sources*, 277, 205-214. https://ui.adsabs.harvard.edu/link_gateway/2015JPS...277..205H/doi:10.1016/j.jpowsour.2014.12.020

⁷³ Federal Chamber of Automotive Industries. (2020). *FCAI Technical statement on EV charging standards for public recharging infrastructure*. <https://www.fcai.com.au/news/codes-of-practice/view/publication/99>

⁷⁴ Australian Energy Market Operator. (2021). Distributed Energy Integration Program—Electric Vehicles Grid Integration. <https://new-energy-guide.aemc.gov.au/distributed-energy-integration-program>

While several international standards describe the communication channels between the grid and EVs, no single set of standards is universally accepted. Australia lacks a regulatory framework that stipulates transparent communication, data exchange and interoperability procedures for achieving system-level coordination and integrating EVs with power grids. A draft of *AS/NZS 4755.3.4*, written in 2013, includes an interface specification for remote agents. This draft deals with the interaction of demand-response enabling devices and electrical products and specifies operational instructions and connections for charge/discharge controllers for EVs and other energy storage devices. However, the draft was never finalised or released for implementation.

Standardisation of communication links to EVs may adversely affect the availability of vehicle models in Australia. A major challenge is the wide range of candidate standards that are not all well-aligned, as each standard has distinct capabilities that overlap with those of other standards. Comparisons between communication standards are difficult due to differences in coverage and intended applications; a comprehensive assessment of features of each standard and how they can support V2G would be necessary before adoption. Below are some notable candidates for Australian adoption.

- Standards covering communication between EVs and EVSE, such as *ISO 15118*, *IEC 61851* and *SAE J3072*
- Standards covering communication between the electricity system and EVSE, such as *IEEE 2030.5*, *OpenADR* and *IEC 61850*
- Standards covering communication between a charging station operator and EVSE, such as *OCPP* and *IEC 63110*

4.5.3 Grid integration

This section examines the unique characteristics and functionality of EVs and EVSE during normal conditions of the grid, and their capability to withstand power system disturbances and mitigate their adverse effects. Research has been conducted on grid-support functions such as voltage and frequency response, keeping the voltage balance between phases, maintaining voltage levels within desired levels, delivering fault ride-through capability, and recovery performance, which specifies the behaviour of EVs/EVSE after an interruption. Integration standards that deal with EV charging/discharging treat the vehicle as a distributed energy resource (DER). The grid interconnection standards for DERs also apply to EV-grid integration. In most countries, the grid support framework for DER is defined by specific grid codes. The *IEEE 1547*, *UL 1741*, and *UL 62109* standards detail the requirements for inverters, converters, controllers, and interconnection system equipment used in DER asset integration into the power grid. In particular, *SAE J3072* defines the requirements for onboard V2G inverters in EVs.

In Australia, *AS/NZS 4777.2:2020*, a standard for grid-connected energy systems via inverters, outlines the expected characteristics and performance of grid-interactive inverters at low voltage and defines the necessary tests to verify their compliance. Thus, access to the network would be restricted to compliant inverters only.⁷⁵ Grid-interactive inverters (that inject power into the grid) are covered by *AS/NZS 4777.2*. This standard does not cover unidirectional chargers and is applied only to bi-directional chargers. However, a recent study at ANU shows that *AS/NZS 4777.2* does not support the contribution of V2G to the FCAS fast services.⁷⁶ In addition, high-capacity inverters and high-voltage connections that are not covered by *AS/NZS 4777.2* may require special consideration. In accordance with the standard, DNSPs are permitted to determine the response-time parameters of their network characteristics within the ranges defined in the standard. To be effective, *AS/NZS 4777.2* must be applied in conjunction with regulations, service requirements, installation requirements, and *AS/NZS 3000* wiring requirements.

Although *AS/NZS 4777.2* covers both on-board and off-board V2G technology, no Australian or international standard exists for unidirectional chargers capable of supplying grid support in the event of an emergency. The

⁷⁵ Standards Australia – electric vehicle. <https://www.standards.org.au/search?q=electric+vehicle&mode=allwords&sort=relevance>

⁷⁶ Mejbaul Haque, Md., Jones, L., Sturmberg, B., & Lucas-Healey, K. (2022, May). *Lessons learnt: Certification and Performance of Charger against AS4777.2:2022 Standard*. <https://arena.gov.au/assets/2022/05/realising-electric-vehicle-to-grid-services-lessons-learnt-2.pdf>

key requirements covered in AS/NZS 4777.2:2020 include harmonic current distortion limits, DC current injection limits, volt-watt and volt-var balance requirements, ramping limits, active/passive anti-islanding protection, under/over-voltage and under/over-frequency protection and measurement accuracy requirements amongst others.

4.5.4 Safety standards

Several organisations define safety standards for EV charging and grid integration. Organisations such as the National Fire Protection Association (NFPA) and the National Electrical Code (NEC) focus primarily on safety measures. In Australia, to ensure the safe charging/discharging of EVs and reliable operation of the EVs in the network, the following standards and regulations (and potentially others) should be taken into consideration.

- *AS/NZS 3820—Essential Safety Requirements for Electrical Equipment*. This is the general electrical safety standard. All electrical equipment imported and sold in Australia must be proven to be electrically safe, and all electrical products, regardless of use, must comply with AS/NZS 3820.
- Work Health and Safety Act. This requires eliminating, or if that is not reasonably practicable, minimising the electrical risks so far as is reasonably practicable.
- *AS/NZS 4417.2—Regulatory compliance mark (RCM) for electrical and electronic equipment*. This stipulates that EVs must be electrically safe, meet the relevant standard, and be covered by a responsible supplier's declaration before being placed on the market.
- Australian Communications and Media Authority (ACMA) Compliance. As almost all EV charging stations have built-in radio transmitters with an integral antenna for 3G, 4G or 5G, Bluetooth, Wi-Fi, and RFID, they need to meet and comply with the ACMA requirements of the RCM, as detailed in AS/NZS 4417.2.
- *AS/NZS 3000:2018—Wiring rule requirements of EV charging station design*
- *AS IEC 62196.2:2014—Plugs, socket outlets, vehicle connectors of EVs*
- *AS/NZS 3112—Approval and test specification—Plugs and socket-outlets*
- *AS/NZS 60335.1—Household and similar electrical appliances safety*
- Overcurrent Protection. Each charger should be supplied individually by an overcurrent protective device complying with AS/NZS 60898, AS/NZS 61009 or AS/NZS 60947.
- AS/NZS 61439 series for test and related requirements for low voltage switchgear and control gear assemblies
- *AS/NZS 3760:2010—In-service safety inspection and testing of electrical equipment*

5 National consultation and engagement

The purpose of the national consultation was to engage with key stakeholders on the topics of managed charging and V2G. The outcomes would inform the design of a potential demonstration project that can support the adoption of V2G and managed charging, and deliver a range of benefits associated with these services. Delivered by the UTS Institute for Sustainable Futures and Curtin University's CUSP Institute, this phase of the research involved:

- Undertaking a literature review to critically assess factors that will likely affect the uptake of V2G and managed charging in Australia, and that could be considered as part of the design of future trials
- Convening a steering group and industry reference group (IRG) to provide feedback and guidance during the project
- Consulting with key stakeholders to identify the most important factors needed to build confidence in V2G and managed charging. This consultation comprised of
 - Seventeen one-to-one interviews with government agencies, energy companies, network operators, industry, industry associations and government. Current and past EV-grid integration trials in Australia were also consulted to identify research priorities for future trials.
 - Three online workshops that were attended by industry partners, IRG members and other participants selected from the targeted interviews.
- Reviewing the findings from other RACE for 2030 projects relevant to V2G and managed charging

The key learnings from the national consultation are summarised as follows:

- There has been an overfocus on early user groups, which are likely to behave differently to the majority of users.
- Projects are needed that can unlock scalability/replicability.
- The immaturity of V2G brings risks to trials for bi-directional charging (V2H, V2B) that could be worth exploring if the risks can be managed.
- An approach is needed that integrates the behavioural aspects and price signals with energy system and network impacts.
- The costs and benefits to customers/businesses still need to be understood for specific customer use cases.
- Accelerating the path to replicability and scalability requires leveraging existing projects or capital works/asset investment.

The following chapter describes the methodology and research findings and provides a summary of the key outcomes from the national consultation and engagement phase.

5.1 Industry reference group (IRG) and steering group

The IRG was formed at the start of the project and made up of organisations selected for their expertise and interests in the EV sector. The purpose of the IRG was to ensure that the views and priorities of industry, government and other key stakeholders were considered throughout the course of the project, and to act as an advisory body to the project team and provide guidance where needed. The IRG constituted a representative from each of the project team members, a representative from RACE partners who wished to attend, and a representative from invited non-RACE partners. It was co-chaired by UTS/Curtin University and two meetings were held over the course of the 6-month project.

The IRG members were drawn from the following organisations:

- AGL Energy
- Ausgrid
- AEMO
- Australian Renewable Energy Agency (ARENA)—
EV integration working group
- JetCharge
- CSIRO
- Endeavour Energy
- Energy Consumers Australia
- Essential Energy
- EV Council
- Horizon Power
- NSW Government
- Planet Ark Power
- Powerlink
- Rectifier Technologies
- Starling Energy Group Pty Ltd
- Tritium
- VW Group (Audi)
- Western Power

The steering group was formed prior to the IRG and made up of key researchers from the project, RACE for 2030 and representatives from AEMO.

- AEMO
- Curtin University
- RMIT University
- Griffith University
- Monash University
- UTS

Steering group members are usually drawn from RACE for 2030 partners who have allocated funding. However, as RACE for 2030 provided internal strategic funding for Stage 1 of the My V2X project, there were no project funders.

5.2 Consultation with key stakeholders

An initial assessment of key stakeholder groups was based on discussions between the project team and RACE for 2030. The stakeholder mapping targeted engagement with those who could help inform the research and would potentially be interested in participating in later stages.

Table 4 below outlines the identified stakeholder groups. The table acts as a summary and tracking sheet, while the status of the discussions was maintained as a live document by the project team during the course of the project.

Table 4: Stakeholder groups identified during national consultation

Stakeholder group	Description
Host	Provides the site, hosts the charge points, captures some/all of the revenue
Electricity network service provider	Responsible for the distribution or transmission of electricity
Energy retailer	Retails energy but may also offer EV and/or charging bundles
Charge point operator	Manages charge point installation, operation, maintenance, etc.
Electric vehicle supply equipment (manufacturer)	Manufactures charging equipment
EVSE vendors (specify, supply, sell, install)	Specify, sell, supply, arrange installation of charging equipment
Auto OEM	Manufactures and sells EV auto vehicles

Software/platform provider	Software and platforms for managing access, payments, fleet, etc
Markets and regulation	Other types of national/NEM bodies responsible for markets or regulations relevant to EVs
State government	State governments with targets/obligations for transport decarbonisation
Local government	Number of councils and their joint/regional organisations seeking to lead on EVs or obligations for transport decarbonisation
Peak body	Represents the industry on topics relevant to EVs
Research	Undertaking research on V2X

Stakeholder engagement activities

The stakeholder engagement activities are the different methods of engagement and participation that were employed. These are summarised in the following table.

Table 5: Stakeholder engagement activities undertaken during national consultation

Engagement activity	Purpose	Target group	Details
IRG meeting	One-to-many meetings to present project plan and confirm research objectives, approach; opportunity for Q&A	IRG members (RACE and non-RACE partners)	2-4 meetings held intermittently (by video call)
One-to-one meeting/call	One-to-one meetings to discuss more detailed aspects of the research	IRG members Other industry players	Follow on from 1st IRG meeting Follow up with IRG members who raised key points Follow up with others identified as important to speak with Target 10 calls
All partner presentation	One-to-many meetings to present research findings and outcomes	RACE for 2030 partners	Final presentation to present results

Consultation with key stakeholders was undertaken to identify specific aspects to accelerate the path to replicability and scalability of V2X performance and managed charging that was perceived to be important to RACE for 2030 CRC partners across the EV and grid value chain. This included government agencies, energy companies, network providers and industry. Discussions were also held with those who had already participated in EV-grid integration trials, with the aim to build on past research and identify areas that would require further investigation. An initial assessment of key stakeholder groups based on mapping of the EV ecosystem by the project team is shown in Table 6.

Table 6. Description of stakeholder groups relevant to the project scope

Stakeholder group	Description	Example
Host	Provides the site, hosts the charge points, captures some/all of the revenue	Local government
Electricity network service provider	Responsible for the distribution or transmission of electricity	Ausgrid
Energy retailer	Retails energy but may also offer EV and/or charging bundles	AGL
Charge point operator	Manages charge point installation, operation, maintenance etc.	Jetcharge
Electric vehicle supply equipment (manufacturer)	Manufactures charging equipment	Rectifier Technologies
EVSE vendor (specify, supply, sell, install)	Specify, sell, supply, arrange installation of charging equipment	Jetcharge
Auto OEM	Manufacturers and sells EV auto vehicles	VW Group
Software/platform provider	Software and platforms for managing access, payments, fleet, etc.	Chargefox
Markets and regulation	Other types of national/NEM body responsible for markets or regulations relevant for EVs	AEMO
State government	State governments with targets/obligations for transport decarbonisation	NSW Government
Local government	Number of councils and their joint/regional organisations seeking to lead on EVs / obligations for transport decarbonisation	Lake Macquarie City Council
Peak body	Represents the industry on topics relevant for EVs	EV Council
Research	Undertaking or funding research on V2X	RACE for 2030

Seventeen bilateral telephone/video calls took place with stakeholders as part of the research (drawn from the table above). While time was limited for the consultation, stakeholder discussions were prioritised by focusing on those in the IRG who raised points during meetings that would benefit from further discussion or those who had been identified as particularly critical to speak with for other reasons. Key findings from the national consultation were presented to the IRG and agreed upon and are expanded on below.

There has been an over-focus in trials on early user groups, who are likely to behave differently from the majority of users. Due to the early-stage nature of the EV market in Australia, most trials have included participants with a higher propensity for risk and those who have a greater attraction to newer, more expensive technology products or services. This is difficult to avoid, but future trials will inevitably see more mass-market customers become participants as the EV market grows and prices fall. However, further consideration should be given to how the views of these customers—who are critical for understanding how EV grid integration

will work at scale—can be elicited in the short term. Fleet vehicle users who are not ready to buy an EV but are interested in trialing one through a vehicle depot could be a good proxy for a better understanding of customers' attitudes toward the mass market.

There is a need for projects that can unlock scalability/replicability. Focussing on small customer niches could lead to research findings with limited applicability at scale, or with limited potential for replication. However, some specific customer groups, while small, may lead to lessons that can unlock other, larger segments of the market. This bootstrapping approach could be successful, but a deep understanding of the market trends and customer behaviour and attitudes will be needed.

The immaturity of V2G brings risks to trials for bi-directional charging (V2H, V2B), but such trials could be worthwhile if the risks can be managed. The ActewAGL and AGL trials both sought to prove the ability of EVs to generate revenue from providing grid services. However, the trials faced operational, regulatory and supply chain issues that demonstrated the challenges of V2G in a market that is not yet ready for it. With many unanswered questions for integrating EVs in the grid through managed charging approaches, exploring V2G in a trial in the short term (next 2-3 years) is likely to yield limited benefits given the risks. However, there could be a case for exploring vehicle-to-home/vehicle-to-building options if the risks related to regulations, standards and supply chains can be managed. Further V2G trials in Australia are needed, but these must involve the CCS charging standards and is not expected to happen in the short-term, considering the necessary certification and approvals.

An approach is needed that integrates behavioural aspects and price signals with energy system and network impacts. Despite the previous EV grid integration trials and some promising early results, further research is still needed to generate more data on how EV users respond to price signals and tariff structures to shape their charging behaviour, and the resultant impacts on the network and energy system.

The benefits and costs of V2G to customers/businesses still need to be understood for specific use cases. Past trials have investigated the costs and benefits for those currently in the EV and grid value chain and now needs to be extended to a wider variety of customer use cases and contexts. How different business models that can re-distribute the risks and drive benefits for consumers, businesses, communities and the grid still requires a deeper understanding.

There is a need to leverage existing projects or capital works/asset investment in order to accelerate the path to replicability and scalability. Accelerating the pathway to scale will require the exploration of a strategic selection of customer use cases. Choosing project partners who have already progressed with integrating EVs in their homes, businesses, depots, government jurisdictions and grids can accelerate the rate at which trials can be deployed and scale can be achieved.

5.3 Australian V2X trials and research

Bi-directional charging is still at a very early stage in Australia. The only vehicles currently available in Australia that can support it are the Nissan Leaf BEV and Mitsubishi's Outlander and Eclipse Cross PHEV, which use the CHAdeMO charging standard. However, the majority of EVs sold in Australia and globally use the Combined Charging System (CCS) standard, which does not currently support bi-directional charging (and is not expected to until 2025/2026).

To date, there has only been one trial of V2G in Australia—the ActewAGL Realising Electric Vehicles-to-grid Services (REVS) project—funded by ARENA (2020–2023). Using 51 Nissan Leafs connected to bi-directional chargers, the project sought to demonstrate the ability to deliver ancillary services to the grid using EVs, while paving the way for increased adoption of V2G. The REVS project ends in March 2023, and at the time of writing its goal to deliver revenue from FCAS at fleet scale appears to have proved elusive. Nevertheless, it has been crucial in understanding the realities of implementing V2G in the current market, while building capacity and fostering collaboration along the EV-and-electricity value chain.

Other EV trials undertaken in Australia over the last decade have focussed on consumer experience and grid integration through time-of-use tariffs (TOU) and managed charging. This includes those led by Origin Energy,

AGL, Jemena, Energex and Ausnet Services. Further trials have since been announced by the South Australian Government in February 2023, but these are still at an early stage.

The following provides a summary of research and consultation programs that have assessed consumer and business perceptions and attitudes towards managed charging and V2G. The summary includes an overview of the type of study, the specific research questions investigated, key findings, and the status (if applicable) of the project or research. These have also been used to inform the research questions and develop a scope for future stages of an EV-grid integration demonstration project.

5.3.1 Incentives and concerns about vehicle-to-grid technology expressed by Australian employees and employers [Research Study—NSW]⁷⁷

Overview: Transport researchers surveyed the perceptions and attitudes related to V2G technology among employees and employers of large organisations, who were questioned via an online survey. The study aimed to inform how incentives and government support may increase the adoption of V2G and managed charging technology.

Questions	<ul style="list-style-type: none"> • [Incentives] How might government support and other incentives encourage the uptake of V2G technology? • What are the perceptions and attitudes of employees and employers toward V2G technologies?
Key Findings	<ul style="list-style-type: none"> • Awareness of V2G technology among employees and employers in various industries is low (only 20% of respondents were informed to any degree). • Potential EV customers are attracted to the idea of reducing the upfront costs of managed-charging technology implementation. • Respondents believed managed V2G technologies to be a long-term cost-saving tool that reduces their transportation costs and placed less importance on sustainability benefits. • Businesses with vehicle fleets and staff parking expressed concern about the degree of V2G infrastructure utilisation, given the upfront costs.

5.3.2 Realising Electric Vehicle-to-Grid Services Interim Social Report, ACT (ARENA)⁷⁸

Overview: Thirty-five in-depth interviews were conducted with participants from target groups involved in V2G.

Partners: Icon Retail Investments Limited, AGL ACT Retail Investments, Australian National University, ACT Government, SG Fleet Australia, JET Charge, Nissan Motor Co., Icon Distribution Investments Limited, Jemena Networks

⁷⁷ Gong, S., Hin Sing Cheng, V., Ardeshiri, A., & Rashidi, T. H. (2021). Incentives and concerns on vehicle-to-grid technology expressed by Australian employees and employers. *Transportation Research Part D: Transport and Environment*, 98, 102986. <https://doi.org/10.1016/j.trd.2021.102986>

⁷⁸ Lucas-Healey, K., Jones, L., Strumberg, B., & Ransan-Cooper, H. (2021). *Interim Social Report from the Realising Electric Vehicle-to-grid Services (REVS) trial*. <https://arena.gov.au/knowledge-bank/revs-interim-social-report/>

Questions	<ul style="list-style-type: none"> • What are the perspectives of key stakeholders involved in the REVS trial on managed charging and V2G? • Why are stakeholders interested in V2G, what are their expectations of the trial, and what are their views of different use cases for bi-directional charging? • How can V2G technology provide contingency FCAS to the NEM (utilising storage in EVs)? • What road mapping exercises are required for mass deployment of the full value stack of V2G services?
Key Findings	<ul style="list-style-type: none"> • Stakeholders are unclear about potential users and beneficiaries of V2G technology. • Many practical aspects surrounding bi-directional charging require further consideration. • Fleet managers are not a homogenous group; they have different needs and motivations. Private EV users are open to V2G, but only under certain conditions. There is a lack of trust in energy providers and the underlying technology.

5.4 International V2X trials and research

5.4.1 What do consumers think of smart charging? Perceptions among actual and potential plug-in electric vehicle adopters in the United Kingdom [Research Study—UK]⁷⁹

Overview: Researchers from the British Transport Research Laboratory (TRL) conducted semi-structured interviews with current and prospective users of plug-in electric vehicles to determine attitudes towards, and perceptions of, managed charging.

Partners: UK Energy Technologies Institute and Transport Research Laboratory

Questions	<ul style="list-style-type: none"> • What are current and potential plug-in electric vehicle users' perceptions of managed charging concepts such as <i>user-managed charging</i> (UMC) (i.e. ToU tariffs) and <i>supplier-managed charging</i> (SMC)? • What specific aspects of UMC and SMC are either appealing or off-putting to electric vehicle users?
Key Findings	<ul style="list-style-type: none"> • Users expressed a preference for UMC over SMC. SMC was perceived to primarily benefit the utility rather than the consumer. • Certain users expressed a lack of trust in suppliers/utilities to manage SMC reliably. Yielding personal control over the timing of charging was seen as a disincentive to using V2G services. • Ceding control to suppliers creates uncertainty for users: would their vehicle be charged when they needed it to be (e.g. in an emergency)? • A two-thirds majority of interviewed users expressed a preference for UMC over SMC. UMC was seen to represent greater control and greater savings, and was easier to understand. • Researchers noted that, in designing a compelling MC value proposition, not only must customer benefits be identified, but any potential disadvantages must also be addressed.

⁷⁹ Delmonte, E., Kinnear, N., Jenkins, B., & Skippon, S. (2020). What do consumers think of smart charging? Perceptions among actual and potential plug-in electric vehicle adopters in the United Kingdom. *Energy Research & Social Science*, 60, 101318. <https://doi.org/10.1016/j.erss.2019.101318>

5.4.2 Navigating expert scepticism and consumer distrust: rethinking the barriers to V2G in the Nordic region [Research Study—Nordic Countries]⁸⁰

Overview: Danish and UK researchers conducted 227 semi-structured interviews related to transport and energy technology policy and practice with diverse stakeholders across government, academia and industry. Experts came from Denmark, Norway, Sweden, Iceland and Finland.

Questions	<ul style="list-style-type: none"> [Barrier Identification] What do relevant experts contend are the key barriers currently to the adoption of V2G and managed charging models?
Key Findings	<ul style="list-style-type: none"> The majority of experts expressed a high degree of scepticism surrounding the benefits and technical viability of managed charging. Concerns were grouped by researchers into four clusters: i. preference for other technologies (such as pumped hydro, grid-scale batteries, or aggregated, second-hand EV batteries), ii. Consumer resistance/lack of awareness and battery degradation, iii. Poor business case and cost & complexity and iv. Insufficient EV volume and electricity market structure. Many experts believed the current concepts of V2G to be “overly complex and costly” from a technical and regulatory perspective. Authors identified a possible disconnect between positive academic literature on V2G and the industry and regulatory actors who are required to make such technologies work commercially.

5.4.3 A fresh look at V2G value propositions—Cenex and Innovate UK [Focus Group Research—UK]⁸¹

Overview: This exploratory report investigated potential value propositions around V2G and managed EV charging. A selection of value propositions was put to customer focus groups comprising domestic (electric vehicle owners) and commercial (fleet or energy managers) audiences. The primary purpose of the focus group sessions was to gather ‘face value opinions’ of the various propositions by non-expert stakeholders.

Questions	<ul style="list-style-type: none"> Based on the experiences of V2G projects, what value can managed charging services deliver to stakeholders in order to develop the V2G industry in the UK?
Key Findings	<ul style="list-style-type: none"> A key value proposition of interest for both focus groups was ‘revenue generation,’ however, the consumer group was concerned about the return on investment associated with managed charging offerings. A second value proposition-‘benefit to society’-related to engaging with managed charging offerings for altruistic reasons, i.e. supporting decarbonisation of the energy system and tackling climate change. Consumers were supportive of the idea provided there was no cost to them and that the issue of EV battery degradation was addressed.

5.4.4 Willing to participate in V2G? Why not! [Research Study—Germany]⁸²

Overview: German researchers investigated the willingness of EV users to participate in V2G charging offerings. Six hundred and eleven vehicle users (including fourteen users of EVs) were surveyed using a choice experiment.

⁸⁰ Noel, L., Zarazua De Rubens, G., Kester, J., & Sovacool, B. K. (2019). Navigating expert skepticism and consumer distrust: Rethinking the barriers to vehicle-to-grid (V2G) in the Nordic region. *Transport Policy*, 76, 67-77. <https://doi.org/10.1016/j.tranpol.2019.02.002>

⁸¹ Cenex. (2022). Project Sciurus: Domestic V2G Demonstration. <https://www.cenex.co.uk/projects-case-studies/sciurus/>

⁸² Geske, J., & Schumann, D. (2018). Willing to participate in vehicle-to-grid (V2G)? Why not! *Energy Policy*, 120, 392-401. <https://doi.org/10.1016/j.enpol.2018.05.004>

Questions	<ul style="list-style-type: none"> • What determines the willingness of vehicle users to make their EV battery available for V2G-based services? • Which technical or economic aspects of managed charging models are most significant in convincing users to participate?
Key Findings	<ul style="list-style-type: none"> • Prior awareness of V2G was considered a major factor in users' willingness to participate in managed charging schemes. Prior awareness was thought to correlate with reduced apprehension surrounding 'new' V2G technology. • Range anxiety was considered a key determinant of user acceptance of V2G and managed EV charging. Should charging be postponed by a utility for grid purposes, the EV battery might contain insufficient charge for a user's requirements, thereby generating anxiety. • Users were favourably inclined to a "reserved minimum range", i.e. a user-nominated minimum vehicle range beyond which managed charging aggregators could not utilise the battery for grid purposes. • Managed charging services should be tailored by V2G aggregators to each EV user's needs. • The disincentive of potential battery degradation for user V2G acceptance was unclear.

5.4.5 Willingness to pay for V2G electric vehicles and their contract terms [Research Study—United States]⁸³

Overview: Researchers surveyed 3029 respondents to evaluate attitudes toward signing V2G charging contracts with specific requirements between drivers and a grid power aggregator.

Questions	<ul style="list-style-type: none"> • Are consumers receptive to the notion of selling their power to the grid, and at what price? • Is the fact that vehicles are driven for only a small part of each day a primary reason for users to participate in V2G schemes?
Key Findings	<ul style="list-style-type: none"> • Respondents indicated a clear preference for up-front remuneration for V2G participation over restrictive contracts with annual cash payments. Drivers prioritised flexibility ahead of long-term commitments. • Drivers viewed V2G contracts as inconvenient and devalued revenue over convenience. A higher price would be demanded to participate in managed charging contracts over earn-as-you-go models.

5.4.6 Shift Trial (UK)⁸⁴

Overview: A collaborative smart charging trial designed to explore various market mechanisms that might shift EV charging demand away from peak periods that concluded in October 2021. This trial appeared to focus on V1G charging, as distinct from bi-directional or V2G technology. Customers were surveyed on their attitudes to smart charging.⁸⁵

Partners: Octopus Energy, Kaluza, ev.energy

Questions	<ul style="list-style-type: none"> • What market-led, scalable smart charging solutions can be designed with a view to widespread roll-out soon? • What is the response of customers to the trial propositions and network impacts?
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⁸³ Parsons, G. R., Hidrue, M. K., Kempton, W., & Gardner, M. P. (2014). Willingness to pay for vehicle-to-grid (V2G) electric vehicles and their contract terms. *Energy Economics*, 42, 313-324. <https://doi.org/10.1016/j.eneco.2013.12.018>

⁸⁴ UK Power Networks. (2022). Shift. <https://innovation.ukpowernetworks.co.uk/projects/shift/>

⁸⁵ Ibid

	<ul style="list-style-type: none"> • How can processes, systems and commercial arrangements be tested to enable widescale smart charging across the UK grid?
<i>Key Findings</i>	<ul style="list-style-type: none"> • Customers were open to open to smart charging as long it didn't interfere with their mobility requirements. • Viable smart charging/grid flexibility mechanisms were proven that will allow for further expansion to other customers.

5.4.7 Parker Project (Denmark)⁸⁶

Overview: This trial, which concluded in January 2019, aimed to show that EVs, as a component of vehicle fleets, can support the electricity grid as a vertically integrated resource via the provision of grid services. It aimed to overcome market, technical and consumer challenges to V2G adoption. Consultation occurred in relation to possible distribution service operator market structures that could utilise V2G services. Five experts were asked to provide feedback on the best market models to fully harness V2G technology in the context of the grid.

Partners: Mitsubishi Motors, Groupe PSA, Nuvve, Isero, ENEL, PowerLabDK

<i>Questions</i>	<ul style="list-style-type: none"> • How can current EVs participate in advanced smart grid service via V2G technology? • Can the trial highlight potential grid applications, grid readiness and scalability/replicability?
<i>Key Findings</i>	<ul style="list-style-type: none"> • The trial proved that project vehicles and charging infrastructure are technically able to provide all frequency regulation services used in Denmark. • It concluded that V2G technology is scalable, and a field test in Copenhagen showed that it can be commercialised. • Further developments were seen to be required to allow for universal support of V2G across all EV brands and markets.

5.4.8 Electric nation vehicle to grid trial (UK)⁸⁷

Overview: The project is recruiting 100 participants for a real-world V2G trial that will allow distribution network operators (DNOs) to better understand the role of bi-directional smart charging as a service across the electricity network. Up to five energy supplier strategies will be tested to reflect a realistic V2G scenario. Consultation of participants occurred during the first phase of the project, which focused on V1G smart charging. Surveys enquired as to participants' work and charging patterns, interest in renewable energy, and vehicle preference.

Partners: Western Power Distribution, CrowdCharge, Drive Electric, EA Technology

<i>Questions</i>	<ul style="list-style-type: none"> • What is the impact of V2G charging on the low voltage (LV) electricity network? • To what extent can V2G assist with the management of LV network demand? • How might dynamic bi-directional energy services from a variety of energy suppliers impact LV network infrastructure?
<i>Key Findings</i>	<ul style="list-style-type: none"> • The project reported a success in implementing V2G from both technical and customer engagement perspectives⁸⁸.

⁸⁶ Parker. (2019). Parker Project. <https://parker-project.com/>

⁸⁷ Electric Nation. (2022). Electric Nation Vehicle to Grid. <https://electricnation.org.uk/>

⁸⁸ Electric Nation. (2022). Home energy bills reduced significantly by Electric Nation Vehicle to Grid project. <https://electricnation.org.uk/2022/06/21/home-energy-bills-reduced-by-vehicle-to-grid-project/>

5.4.9 Project Sciusus (UK)⁸⁹

Overview: This V2G project, run by Cenex UK, was designed to validate the technical and commercial viability of domestic V2G charging solutions. Three hundred and twenty domestic V2G charge points were installed across the UK. Consultation occurred via participant insight surveys. Many concerns expressed by participants prior to the trial (e.g., battery degradation, reliability, car being uncharged) were alleviated after the completion of the trial. Confidence in the V2G technology increased significantly. The three-year trial concluded in May 2021.

<i>Questions</i>	<ul style="list-style-type: none">• How can V2G technology be made to work at the residential level?• Can a business case be made for residential customers participating in and benefiting from a V2G service?• Can the value of V2G be demonstrated for vehicle manufacturers?
<i>Key Findings</i>	<ul style="list-style-type: none">• The project found that maximal V2G benefit for organisations is achieved by identifying and targeting the right customer ‘archetype’, i.e. one with an adequately sized EV battery using a technological platform best able to capture value from required grid services and wholesale price spikes.• Customer engagement is crucial to allow them to understand the benefits V2G can provide to them individually.

5.5 Australian academic research

In the academic environment, both RMIT and Griffith universities have developed bi-directional chargers for V2G applications. Griffith University, in collaboration with Planet Ark Power (as an industry partner), developed a bi-directional DC/AC inverter as V2G on-board charger (OBC) in 2018. This unique, three-in-one multifunctional on-board charger can provide three ancillary functions, including voltage regulation, reactive power support, and current harmonic elimination while operating in G2V/V2G mode. The prototype of the EV charger has a compact design and a decreased power loss due to using SiC-based MOSFETS and a high-efficiency, high-frequency coaxial transformer (HFCT). It also causes lower battery stress because it employs an interleaved, two-leg buck-boost DC/DC converter (ITBBC). Different operational modes of the EV charger and its improved performance are validated through both simulation and experimental results. The power electronic circuit includes three-stage converters, using an AC/DC converter to connect AC-side (grid), an isolated DC/DC converter with an isolation transformer, and ITBBC. The three-stage converters operate as a 4 kVA V2G-OBC in a bi-directional mode to charge and discharge a 400 V EV battery. The proposed EV charger (as shown in Figure 8) is a newly developed V2G-OBC system (integrated with STATCOM and APF functions) suitable for commercialisation.



Figure 8. Prototype of the bi-directional EV charger developed at Griffith University

⁸⁹ Cenex. (2022). Project Sciusus: Domestic V2G Demonstration. <https://www.cenex.co.uk/projects-case-studies/sciusus/>

6 Conclusion and the Australian research gaps

Certain challenges and opportunities in the uptake of EVs are unique to Australia and relate to the way the electricity market operates and the lack of incentives to increase the penetration of EVs. Nevertheless, given the current high cost of petrol and diesel, as well as the declining prices of EVs and associated equipment, it is expected that the uptake of EVs will increase rapidly during the next 5–10 years. Additionally, the more ambitious GHG reduction targets of the current federal government may see the legislation of new incentives to increase the uptake of DER and EVs.

Another factor likely to increase interest in EVs is that due to the COVID-19 pandemic, many people have chosen to work from home, which means they do not need to commute to work. This means that a substantial number of EVs will be completely recharged at the end of the business day because their owners have rooftop solar and/or may not have used their car during the day as they have been working from home. This trend is likely to continue to a certain degree. Combining this with the fact that Australia has one of the highest penetrations of rooftop solar in the world will see opportunities for EV owners to charge their EVs with their own solar power. While a typical rooftop solar system of 5 kWp will not have sufficient capacity to completely recharge a typical EV in a single day, most EV owners will only use a fraction of their EV battery capacity during the week, unless they go on a long-distance trip. If these EVs could participate in a V2G system, then the electricity system could benefit from this virtual power plant with dispatchable power ready for the evening peak in the residential sector. At the same time, EV owners could benefit economically provided that they are properly compensated for the electricity that their EVs export to the grid.

One of the biggest challenges in Australia is that, while the electricity system is highly regulated by various bodies, there are currently no regulations that allow for prosumers with DERs, including battery storage, to be properly compensated if they export electricity to the grid during peak periods and provide specific services such as FCAS to the electricity grid. According to the Australian Energy Market Commission, the implementation of new markets to financially reward prosumers with DER + battery storage has been brought forward to October 2023.⁹⁰ Beyond these rule changes, the Energy Security Board's post-2025 plan will provide new flexible electricity trading arrangements that will remove barriers and facilitate the way for smaller players to engage with the wholesale market.⁹¹ However, one of the challenges with respect to V2G is estimating the economic benefits for grid operators and especially for EV owners. It is still unclear what markets EV owners will be permitted to participate in, how the scheme will be regulated, and how EV owners will be rewarded. Clearly, further practical research and modelling on grid integration of EVs in the Australian market is required to properly assess the benefits of V2X technologies.

6.1 Cost-benefit and regulatory challenges

The key research questions of this section were developed over the course of this project through a national consultation with industry, supplemented with additional desktop research. These questions may form a basis for later stages of practical demonstration but will require further tailoring and translation for specific use cases.

What are the costs and benefits related to managed and bidirectional EV charging?

The complexity of the different approaches to EV charging, combined with the highly dynamic nature of the emerging sector, makes estimating the costs and benefits extremely challenging. Different approaches and business models can simultaneously add value and incur costs, leading to trade-offs that are difficult to assess.

⁹⁰ Australia Energy Market Commission. (2021, July 15). *New plans for batteries cut red tape and boost revenue options*. <https://www.aemc.gov.au/news-centre/media-releases/new-plans-batteries-cut-red-tape-and-boost-revenue-options>

⁹¹ Energy Security Board. (2020, January). *Post-2025 Market Design Directions Paper*. https://view.officeapps.live.com/op/view.aspx?src=https%3A%2F%2Fweb.archive.org/au%2Fawa%2F20210603144613mp_%2Fhttps%3A%2F%2Fenergyministers.gov.au%2Fsites%2Fprod.energycouncil%2Ffiles%2Fpublications%2Fdocuments%2FP2025%2520Market%2520Design%2520Directions%2520Paper.docx&wdOrigin=BROWSELINK

This uncertainty and opaqueness can be further exacerbated by the unknown driving and charging behaviour of EV owners/users, energy market and demand flexibility dynamics, complex integration within buildings and the grid, and interactions with other DER. In addition, customer/end-user behaviour and attitudes to managed and bi-directional charging are still poorly understood. Studies to date have focussed on the easier-to-engage early adopters and innovators among private and fleet EVs.

Global supply chain issues and reliance on overseas suppliers can incur further costs for meeting local standards, which are hard to predict and lead to additional risk.

How will mobile battery energy storage compete with or complement stationary BESS over time?

Stationary storage is already being co-located with EV chargers to ensure available capacity and avoid costly network upgrades. Stationary battery storage for demand flexibility has been deployed at a greater scale to date than EVs for their mobile battery storage. Revenues for providing demand flexibility are variable and difficult to predict. This can be expected to change over time as various forms and levels of stationary and mobile battery storage are deployed.

The mobile nature of EVs makes it more challenging than stationary batteries to predict and control where they will be at any given time. However, if they can be predicted and controlled then this mobility can serve as a major advantage. It could lead to a role for machine learning (ML) and artificial intelligence (AI), which are already being applied in EVs and stationary batteries.

How will managed and bi-directional charging impact EV batteries?

The use of EVs for bi-directional charging can be a risk from the owner/operators view in terms of battery degradation, reduced resale value and increased maintenance requirements. This has implications for warranty and other requirements where bi-directional charging is enabled. Managed charging could also help prolong battery life by optimising how vehicles are charged. Vehicle OEMs are already focused on battery impacts from interaction with loads and the electricity grid. Uncertainty remains over whether and how managed and bi-directional charging will impact the proposition for EVs due to positive/negative effects on the battery system.

What business models and customer propositions are needed for replicability and scale?

The benefits and costs of V2X technologies will vary for different stakeholders, including EV owners, fleet operators, manufacturers, transmission and distribution network service providers, energy retailers and aggregators, regulators, government and the general public. A gap exists between previous and current trials for assessing viable business models for managed and bi-directional charging and the proposition to different stakeholder groups. The focus on innovator/early adopter groups drawn from within private and business EV owners/operators provides an unreflective view of the wider mass market. For example, those from outside metropolitan areas, renters, apartment dwellers, disabled, lower income groups and community groups have so far been unrepresented.

How can we get the policy, regulatory and standards settings right now to avoid future issues further down the line with grid integration of EVs?

Policy, regulation and standards are still evolving, often in an uncoordinated manner. Future regulations will need a holistic, strategic approach that can address a wide variety of issues effectively, from tariff reform and consumer rights to how wholesale market signals could be better conveyed to end-users. A key legal question that may have to be addressed in the future is whether and how EVs can interface with the electricity market other than as consumers, and to what degree this interaction needs to be facilitated and by whom. EVs capable of managed and bi-directional charging offer challenges and opportunities to DNSPs. Consumers also stand to benefit from this, but questions were raised during the research over whether this is possible without a change in roles and responsibilities of DNSPs, or whether the introduction of new roles is needed.

6.2 Technical challenges and barriers

To achieve the maximum potential benefits of the V2G technology and realise the opportunities for applying V2G services in Australia, the following technical difficulties and challenges must be addressed.

A lack of V2G-capable charging infrastructure. Potential V2G services such as frequency regulation require sufficient numbers of charging stations and EVSE equipped with bi-directional chargers. Enough charging hardware is essential for engaging active players. Currently, only a limited number of EVs in the Australian market are capable of providing bi-directional power flow between vehicles and charging stations. There is also limited availability of the V2G-ready EVSE.⁹² Bi-directional charging technology is not available yet in Australia, but a trial backed by the Australian Renewable Energy Agency (ARENA) is underway in Canberra to test the technology.⁹³ A recent survey of consumer attitudes⁹⁴ found that the lack of access to, and perceived inconvenience of, charging stations are key barriers to the adoption of EVs. To alleviate the concerns of consumers and facilitate V2G uptake, Australia needs significant investment in EV-charging infrastructure—especially in the bi-directional chargers—in the coming years.

A lack of standard communication infrastructure. Implementing V2G services and realising their potential benefits will require appropriate and standardised communication infrastructures to transfer the data between EV owners, EV aggregators and network operators. For example, many buildings, especially domestic properties, are not exposed to ToU tariffs or capacity charges that would enable them to optimally schedule V2G charging and discharging. Depending on the type of services intended (e.g. frequency regulation) and the reaction speed required for delivering them, implementing real-time or online telecommunication may be essential.

Insufficient levels of penetration of V2G-enabled EVs. Australia's underdeveloped charging network presents a significant obstacle to widescale EV adoption. Insufficient charging options and range limitations of EVs have been repeatedly cited as key reasons for deciding against an EV purchase. To achieve the maximum benefits of V2G services, enough EVs with this capability must be present throughout the network. Delivering certain services, such as frequency regulation, may be realised only by employing the available battery capacity of thousands of EVs. In other words, the penetration level of V2G technologies will impact the opportunities that could be achieved by the integration of EVs. The communication and control infrastructure required for V2G aggregation is still at an early stage of development and there are few commercial aggregators in the market. Also, currently in 2023 the level of customer awareness of V2G technology is considered low, and the value proposition to end-users is poorly understood. These barriers limit the uptake of EVs with V2G capability.

A lack of active players and market infrastructure who are considering V2G services. To provide some potential V2G services, a sufficient number of EVs needs to participate to deliver the energy to the network. To aggregate the EVs and unify the available battery capacities, the presence of active players such as EV aggregators and active consumers may be essential. The role of these players, and the extent of their activities, should be defined and determined by the power system industry and electricity market environment. Also, grid codes in many countries, including Australia, do not recognise V2G or EVSE as distributed energy storage resources capable of injecting power into the network. The grid interconnection and certification processes are therefore slow, expensive or often prohibited. Appropriate market mechanisms need to be designed and developed, along with the related technical and regulatory infrastructures, to enable the operation and profitability of EVs with V2G capability in the retail or wholesale market environment.

A lack of smart, bi-directional charging algorithms. Uncontrolled electrifying of EVs, especially EVs with V2G capability, will adversely impact the electrical features of the network. To avoid these undesired effects and relieve

⁹² Electric Vehicle Council. (2021, August 23). *State of Electric Vehicles*. <https://electricvehiclecouncil.com.au/reports/state-of-electric-vehicles-2021/>

⁹³ REVS. *Realising electric vehicles to grid services*. <https://secs.accenture.com/accenturems/revs>

⁹⁴ Electric Vehicle Council. (2021, October 10). *Consumer Attitudes Survey*. <https://electricvehiclecouncil.com.au/reports/consumer-attitudes-survey-2021/>

the related challenges and issues, appropriate and applicable control algorithms and approaches for managing the charge and discharge of EVs is essential. Frequency regulation, loss reduction, providing voltage support, improving power quality, providing energy arbitrage, enabling load management, etc. may be realised by implementing coordinated management of EVs.

Comprehensive databases of V2G-enabled EVs are required. The availability of EV data is crucial for network and power system management. Collecting information regarding the number of existing EVs, the rate of charging and discharging, and data related to their participation in V2G services, could inform future network expansion plans and support other active players—like aggregators—with preparing incentive programs to increase EV participation. Providing a comprehensive database, implementing an EV data acquisition system, and setting up a clear data collection process will play key roles in making this happen. To fully capture the potential benefits of EVs with V2G capability, we need to forecast the available capacity of vehicle batteries and extract information regarding the charging and discharging patterns of EV owners. Australia, in particular, has limited empirical evidence on consumer preferences and behaviours regarding EV adoption (especially with V2G capability) and their usage and charging patterns. Empirical research based on stated and revealed preference surveys, as well as bi-directional charging infrastructure usage data, are needed to fill this gap.

Insufficient hosting capacity of the existing network for V2G services. Existing electric networks are not designed to embrace high penetrations of EVs and absorb the impacts of charging and discharging of these technologies. Where networks have insufficient hosting capacity, increasing the EV integration may lead to the overloading of distribution transformers, overhead lines and cables. Therefore, another important factor currently preventing potential V2G services is a lack of network capacity to host the EVs. This feature is dependent on the network configuration, voltage levels, materials and equipment, load consumptions, utilisation factor of components, behavioural patterns of EV owners, etc. The coordinated management of EVs may also impact the network hosting capacity in the short term. Meeting future EV-charging requirements will depend on the modernisation of parts of Australia's energy grid through solutions such as; advanced data-driven algorithms for planning and operation, facilitating the integration of the distribution grid and the FCAS market, and developing non-wire alternative solutions to reduce upgrade costs.

Protection systems to accommodate V2G must be adaptive and intelligent. Delivering V2G services results in bi-directional power flow in the networks. This may impose serious challenges on protection systems designed for unidirectional distribution. V2G-enabled EVs can be significant generators within the distribution grid, which may cause voltage unbalance among phases and can contribute to faults. Further research based on trial results is required for a full understanding of their impact. Implementing an adaptive and smart protection system may alleviate the challenges of V2G services and is a matter of further research.

7 Appendices

Appendix I: Legislative framework of the electricity market

Australian Energy Market Agreement (AEMA)

The Australian Energy Market Agreement (AEMA) is made between the federal and state and territory governments to establish a cooperation framework towards a nationally consistent energy policy. The AEMA recognises that the Ministerial Council on Energy is the policy governance body for the Australian energy market and that it reports to the Council of Australian Governments (COAG). However, on 2 June 2020, COAG was replaced with the National Federation Reform Council (NFCR).⁹⁵ In consideration of the states' autonomy, the AEMA explicitly outlines that “states can develop environmental, energy efficiency and demand management policies, as well as establishing their own framework, to address greenhouse emissions.”⁹⁶

National electricity law

The NEM is governed by national electricity law, which is defined in the *National Electricity (South Australia) Act 1996*.⁹⁷ Participating NEM states have enacted mirror legislation.⁹⁸ State governments (Vic⁹⁹ and NSW¹⁰⁰) have recently enacted further legislation to support their climate response policies and commitments, and to enable projects that will ensure the optimal operation of the NEM.

National electricity rules

The AEMC sets the national electricity rules (NER)¹⁰¹ and has the authority to make changes to these rules, which can be requested by anyone, after a thorough consultation process has been undertaken.¹⁰² Csereklyei et al. (2021) note that the NER cover “the operation of the wholesale electricity market, the regulation of network services, the management of power system security, and connections for electricity customers.”¹⁰³

NEM market participants

Chapter 2 of the NER categorises NEM participants as follows: generators¹⁰⁴, including scheduled generators, non-scheduled generators, market generators, non-market generators, ancillary service generating unit and semi-

⁹⁵ Australian Government Department of Prime Minister and Cabinet. (2020, December 10). *National Federation Reform Council*. <https://pmc.gov.au/domestic-policy/national-federation-reform-council>

⁹⁶ Energy Networks Australia. (2020, July 9). *Are We All Still in Agreement?* <https://www.energynetworks.com.au/news/energy-insider/2020-energy-insider/are-we-all-still-in-agreement/>

⁹⁷ *National Electricity (South Australia) Act 1996*. [https://www.legislation.sa.gov.au/lz/path=%2FC%2FA%2FNATIONAL%20ELECTRICITY%20\(SOUTH%20AUSTRALIA\)%20ACT%2019](https://www.legislation.sa.gov.au/lz/path=%2FC%2FA%2FNATIONAL%20ELECTRICITY%20(SOUTH%20AUSTRALIA)%20ACT%2019).

⁹⁸ National Electricity (Victoria) Act 2005; National Electricity (New South Wales) Act 1997; Electricity—National Scheme (Queensland) Act 1997; Electricity Act 1994 (Qld); Electricity - National Scheme (Tasmania) Act 1999; National Electricity (Tasmania) Law; Electricity (National Scheme) Act 1997 (ACT).

⁹⁹ State Government of Victoria. (2020, February 18). *Victoria acts to secure a more reliable energy system*. <https://www.lilydambrosio.com.au/media-releases/victoria-acts-to-secure-a-more-reliable-energy-system/>.

¹⁰⁰ NSW Government. (2019). *NSW Electricity Strategy*. <https://www.energy.nsw.gov.au/government-and-regulation/electricity-strategy>

¹⁰¹ Australian Energy Market Commission. (2021, May 18). *National Electricity Rules Version 182*. <https://aemc.gov.au/news-centre/media-releases/new-version-182-national-electricity-rules>

¹⁰² Australian Energy Market Commission. (2022). *Changing the Energy Rules – a Unique Process*. <https://www.aemc.gov.au/our-work/changing-energy-rules>

¹⁰³ Csereklyei, S., Kallies, A., & Valdivia, A. D. (2021). The status of, and opportunity for, utility-scale battery storage in Australia: A regulatory and market perspective. *Utilities Policy*, 73, 101313. <https://www.sciencedirect.com/science/article/abs/pii/S0957178721001466>

¹⁰⁴ Australian Energy Market Commission. *National Electricity Rules Version 182—Rule 2.2* <https://aemc.gov.au/news-centre/media-releases/new-version-182-national-electricity-rules>

scheduled generators; customers¹⁰⁵, including first-tier customers, second-tier customers, market customers, ancillary services load, wholesale demand response units, small generation aggregators and demand response service providers; market participants¹⁰⁶, including market customers, market small generation aggregators, demand response service providers, market generators, market network service providers and metering coordinators; network service providers¹⁰⁷, including the market-service network, scheduled-service network, trader and reallocator; and special participants¹⁰⁸, including the system operator or distribution system operator.

¹⁰⁵ Ibid—Rule 2.3

¹⁰⁶ Ibid—Rule 2.4

¹⁰⁷ Ibid—Rule 2.5

¹⁰⁸ Ibid—Rule 2.6

Appendix II: Australian policies table

Initiatives and programs/policies	Author	Content Summary	Link	Comments
Victoria				
Victoria's Climate Change Strategy	DELWP	<ul style="list-style-type: none"> • Roadmap to achieve Net Zero Emissions by 2050 • Five-point plan to reduce emissions • Includes 50% car sales to be EVs by 2030, and new purchases of public buses to be 100% electric by 2025 	https://www.climatechange.vic.gov.au/victorias-climate-change-strategy	
Zero Emissions Vehicles Roadmap	DELWP	<ul style="list-style-type: none"> • Addresses the next 10 years' strategy setting sustainable targets and making strategic investments • Includes EV charging station installation across regional Victoria by 2024 • Victorian Government fleet replacement (400 EVs by 2023) 	https://www.energy.vic.gov.au/renewable-energy/zero-emissions-vehicles https://www.solar.vic.gov.au/zero-emissions-vehicle-subsidy	Executive summary pages 6-8 outline key actions
Gas Substitution Roadmap	DELWP	<ul style="list-style-type: none"> • Addresses enabling choice and removing barriers to electrification • Incentives are aimed at energy upgrades, solar homes, 7-star Homes Program aimed at energy efficiency • Policy and regulatory change to remove VPP gas connection requirements (new residential zones), planning scheme changes to support energy efficiency, align plumbing regulations with NCC 2022 	https://www.energy.vic.gov.au/gas/victorias-gas-substitution-roadmap	

Advancing Victorian Manufacturing—A Blueprint for the Future	DEDJTR	Outlines key features of manufacturing in Victoria, including digitisation, supply chain, involvement in sectors like clean energy, automotive, construction and steel production	https://business.vic.gov.au/grants-and-programs/advancing-victorian-manufacturing	
Advancing Victorian Manufacturing—A Blueprint for the Future	Dept Jobs, Precinct, Regions	<ul style="list-style-type: none"> • The Victorian State Government maintains a focus on locally manufactured products and is currently reviewing its strategies. • The Future Industries Program identifies potential local manufacturer opportunities for Victorian businesses. • New technologies in both transport and energy are viewed as opportunities. 	https://djpr.vic.gov.au/about-us/overview/strategies-and-initiatives/advancing-victorian-manufacturing https://www.budget.vic.gov.au/supporting-victorian-manufacturing https://business.vic.gov.au/grants-and-programs/future-industries	
Victoria's Infrastructure Strategy 2021–2051	Infrastructure Victoria	<ul style="list-style-type: none"> • A 30-year outlook containing 94 recommendations to address pending challenges such as management of urban design, harnessing infrastructure for productivity and growth, developing regional Victoria 	https://www.infrastructurevictoria.com.au/project/30-year-strategy/	
Victorian Infrastructure Plan 2021	Victorian State Government	<p>Response to Infrastructure Victoria's 30-year Strategy</p> <p>Ch 3.1 Transport (30 pages)</p> <p>Ch 3.3 Energy (7 pages)</p> <p>Ch 3.8 Cross sector (5 pages)</p>	https://www.dtf.vic.gov.au/infrastructure-plan	V2G and V2X is an <u>urban planning and mobility project</u> ; electricity supply is planned and designed for where it is needed.
Built Environment Climate Change Adaptation Action Plan 2022–2026	DELWP	<ul style="list-style-type: none"> • Aims to take a systems approach to adaptation 	https://www.planning.vic.gov.au/_data/assets/pdf_file/0037/557389/Built-Environment-Climate-Change-Adaptation-Action-Plan-2022-2026.pdf	

		<ul style="list-style-type: none"> Recognises the interrelationship between built environment and other key systems ¹⁰⁹ 		
NSW				
NSW Climate Change Policy Framework	State of NSW	A high-level framework	https://www.environment.nsw.gov.au/topics/climate-change/policy-framework	Dated 2016. Due to be updated in 2020 – currently pending
Net Zero Plan Stage 1: 2020–2030	DPIE	<ul style="list-style-type: none"> Goal is to reach net zero emissions by 2050 Four priorities are presented: Priority 1 is aimed at encouraging consumer uptake of proven emission reduction and technologies, including EVs and PV Solar 	https://www.environment.nsw.gov.au/topics/climate-change/net-zero-plan	
Electric Vehicle Strategy	DPIE	<p>A 5-point action plan –</p> <ol style="list-style-type: none"> Helping drivers purchase EVs Building an EV charging network Enticing EV uptake through priority road use and local government measures Skills and training to be EV ready Fair and sustainable road funding 	https://www.environment.nsw.gov.au/topics/climate-change/net-zero-plan/electric-vehicle-strategy	
Future Transport Strategy	TNSW	<ul style="list-style-type: none"> Based on six principals that support a shift to agile transport planning and investment, developing technologies, and innovation to support a strong 	https://future.transport.nsw.gov.au/future-transport-strategy	

¹⁰⁹ Victoria State Government—Department of Transport and Planning. (2022). *Built Environment Climate Change Adaptation Action Plan 2022–2026*. https://www.planning.vic.gov.au/_data/assets/pdf_file/0037/557389/Built-Environment-Climate-Change-Adaptation-Action-Plan-2022-2026.pdf

		economy, accessible, safe and sustainable transport system		
Future Energy Strategy (and Future Energy Action Plan)		<ul style="list-style-type: none"> Figure 2 highlights how the energy strategy supports the Future Transport Strategy, which in turn supports climate change mitigation efforts. Chapter 6 describes <i>Mobility as a Service (MaaS)</i> and how cleaner transport technologies (including EVs and electric buses) need to be well integrated to motivate consumers to use them. 	https://future.transport.nsw.gov.au/plans/future-energy-strategy	The documents are very informative for the public.
Connected and automated vehicles (CAV) Plan	TNSW	Outlines how electrifying transport supports MaaS; Infrastructure (e.g, charging of EVs) should support such future developments	https://future.transport.nsw.gov.au/plans/connected-and-automated-vehicles-plan	
NSW Electric and Hybrid Vehicle Plan	TNSW		https://future.transport.nsw.gov.au/plans/nsw-electric-and-hybrid-vehicle-plan	
Electricity Infrastructure Roadmap	Energy NSW	<ul style="list-style-type: none"> State roadmap that outlines the approach to REZ, transmission development and electricity infrastructure safeguards Includes the pumped hydro recovery grants scheme International competitive industries 	https://www.energy.nsw.gov.au/government-and-regulation/electricity-infrastructure-roadmap	
SA				
South Australia's Electric Vehicle Action Plan	Government of South Australia	<p>Presents four action themes –</p> <p>i. State-wide public charging network</p>	https://www.energymining.sa.gov.au/industry/modern-energy/electric-vehicles	Application of charging types (p. 20)

		<ul style="list-style-type: none"> ii. New government fleets to be EVs, research on integrating electric buses to the grid iii. Private and government fleet EV take-up demonstrate smart and two-way charging iv. Establish a SA framework and advocate nationally for EVs 	https://www.energymining.sa.gov.au/__data/assets/pdf_file/0010/609391/DEM-ev-strategy-consultation-report.pdf	
Incentives for electric vehicles	Government of South Australia	<ul style="list-style-type: none"> • \$3000 subsidy for up to 7000 zero-emission vehicles • 3-year motor registration fee exemption on zero emission vehicles • smart charging trials 	https://www.treasury.sa.gov.au/Growing-South-Australia/incentives-for-electric-vehicles https://www.energymining.sa.gov.au/industry/modern-energy/electric-vehicles/smart-charging-trials	
QLD				
Queensland's Electric SuperHighway	QLD Government	Three phase program installing fast charging sites along the coast of QLD and inland to key regional and rural areas	https://www.qld.gov.au/transport/projects/electricvehicles/super-highway https://statements.qld.gov.au/statements/95209 https://statements.qld.gov.au/statements/92421	
Electric Vehicle (EV) Charging Infrastructure: Practice Note	QLD Government	Principles for planning EV charging infrastructure in <i>Priority Development Areas</i> (PDAs) in Queensland to support the selection of the right type of infrastructure at the right location	https://www.statedevelopment.qld.gov.au/__data/assets/pdf_file/0016/18142/practice-note-electric-vehicle-charging.pdf	Department of State Development, Manufacturing, Infrastructure and Planning

Queensland's Zero Emission Vehicle Strategy 2022-2032	QLD Government	<p>Ten-year strategy includes –</p> <ul style="list-style-type: none"> • target of 50% car sales to be zero emission by 2030, 100% by 2036. • 100% QLD Government fleets passenger vehicles to be zero emission by 2026 • new Translink-funded buses to be zero emission from 2025 in SE QLD and 2025–2030 regional QLD 	<p>https://www.qld.gov.au/transport/projects/electricvehicles</p> <p>https://www.aldergrovestar.com/news/translink-funding-plan-includes-skytrain-expansion-electric-buses/</p>	Zero emission vehicle's include hydrogen-fuelled vehicles
Shifting to zero emission vehicles	QLD Government	<ul style="list-style-type: none"> • Vehicle registration duty savings • Purchase rebates 	https://www.qld.gov.au/transport/projects/electricvehicles/hitting-the-road	
Changing the way we travel	QLD Government	Future of transport is MaaS	https://www.qld.gov.au/transport/projects/electricvehicles/changing-the-way-we-travel	
Solar power for your home	QLD Government	Outlines PV solar installation considerations, including grid connection, feed-in-tariffs, battery storage and PPAs	<p>https://www.qld.gov.au/housing/buying-owning-home/energy-water-home/solar</p> <p>www.abc.net.au/news/2022-06-26/queensland-no-household-solar-battery-rebate/101165580</p>	
Electricity	QLD Government	<ul style="list-style-type: none"> • Tariffs, metering • Rebates for multi-unit premises and embedded networks 	www.qld.gov.au/housing/buying-owning-home/energy-water-home/electricity/electricity-prices	

			www.qld.gov.au/community/cost-of-living-support/concessions/energy-concessions/cost-of-living-rebate www.qld.gov.au/housing/buying-owning-home/energy-water-home/electricity/electricity-prices/multiunit-complexes-electricity www.qld.gov.au/community/cost-of-living-support/concessions/energy-concessions/residential-homes-rebates	
WA				
WA's climate action efforts accelerated with \$60 m EV package	Government of WA	<ul style="list-style-type: none"> • \$60 million Clean Energy Car Fund • \$36.5 million for \$3,500 rebates on the purchase of electric and hydrogen vehicles • \$22.6 million committed to more EV charging infrastructure across the state 	http://www.mediastatements.wa.gov.au/Pages/McGowan/2022/05/WAs-climate-action-efforts-accelerate-with-60-million-dollar-EV-package.aspx https://www.transport.wa.gov.au/projects/zero-emission-vehicle-zev-rebate.asp	
Policy advisers to WA Government	Government of WA	<ul style="list-style-type: none"> • Distributed Energy Resources Roadmap • EV Action Plan August 2021 	https://www.wa.gov.au/organisation/energy-policy-wa https://www.wa.gov.au/government/distributed-energy-resources-roadmap	

			https://www.wa.gov.au/government/publications/electric-vehicle-action-plan-preparing-was-electricity-system-evs	
	Government of WA	<p>Generation, transmission, distribution, customer</p> <p>Next critical stage priorities –</p> <ul style="list-style-type: none"> • Implementing the Energy Transformation Taskforce decisions • Integrating new technology into the power system • Keeping the lights on as the power system transitions • Regulating for the future 	https://www.wa.gov.au/organisation/energy-policy-wa/energy-transformation-strategy	
State Electric Vehicle Strategy for Western Australia	Government of WA	<p>Priority Action Areas include:</p> <ul style="list-style-type: none"> • EV uptake • Infrastructure charging and refuelling • Standards, guidelines and planning • Industry development 	<p>https://www.wa.gov.au/service/environment/environment-information-services/electric-vehicle-strategy</p> <p>https://www.wa.gov.au/system/files/2020-11/State_Electric_Vehicle_Strategy_for_Western_Australia_o.pdf</p>	
A Guide to electric vehicles	Government of WA	<ul style="list-style-type: none"> • Comprehensive guide that includes country policy comparisons and OEM comparisons • Acknowledges that OEMs are phasing out internal combustion engine (ICE) driven vehicles 	https://www.wa.gov.au/government/publications/guide-electric-vehicles	This OEM shift directly impacts on Australian manufacturing, infrastructure, jobs, skills, the NEM, SWIS,

				and other Australian electricity grids
Western Australian Electric Vehicle Charger Map	Government of WA	Intended locations for charging stations	https://www.wa.gov.au/government/publications/western-australia-electric-vehicle-charger-map	
Western Australia's Future Battery Industry Strategy	Government of WA	<p>Outlines WA's plans with respect to the whole supply chain, including battery mineral explorations and mining, processing, component and cell manufacturing</p> <p>Five priorities:</p> <ol style="list-style-type: none"> i. Growing WA participation in global supply chains ii. Promoting investment opportunities iii. Certifying WA battery minerals iv. Supporting energy storage applications v. Developing local capability 	<p>https://www.wa.gov.au/organisation/department-of-jobs-to-urism-science-and-innovation/western-australias-future-battery-industry</p> <p>https://www.wa.gov.au/government/publications/battery-and-critical-minerals-prospectus</p> <p>https://www.wa.gov.au/government/publications/western-australias-future-battery-industry-strategy</p>	WA is a hub for critical minerals that are used in a wide range of battery types.
Wholesale Electricity Market WA (WEMWA)	Economic Regulation Authority (ERA)	Economic regulation of the wholesale electricity market	https://www.erawa.com.au/electricity/wholesale-electricity-market	
Synergys Regulatory Scheme	ERA	Includes requirements for ringfencing, business segregation, transfer pricing, non-discriminatory wholesale electricity trading and the provision of standard products	https://www.erawa.com.au/electricity/wholesale-electricity-market/synergys-regulatory-scheme	

Grant assistance and programs register for WA industry	Government of WA	Outlines a broad range of state and federal funding programs for proponents	https://www.wa.gov.au/organisation/department-of-jobs-Tourism-science-and-innovation/grants-assistance-and-programs-register-wa-industry	
Solar energy generation	Government of WA	The state government is diversifying investment into other forms of clean energy (wind and storage) to balance the effect of high levels of rooftop solar	https://www.brighterenergyfuture.wa.gov.au/solar-energy-generation-2/ https://www.brighterenergyfuture.wa.gov.au/whole-of-system-plan/	
Whole-of-system plan	Government of WA	20-year outlook on the future of the SWIS	https://www.wa.gov.au/government/publications/whole-of-system-plan-report	
NT				
Roadmap to renewables	NT Government		https://territoryrenewableenergy.nt.gov.au/about/roadmap-to-renewables	
Electricity system plans	NT Government	<ul style="list-style-type: none"> • Darwin-Katherine electricity system plan • Alice Springs Future Grid Roadmap to 2030 • Remote power system strategy 	https://territoryrenewableenergy.nt.gov.au/strategies-and-plans/electricity-system-plans	
Electric vehicle strategy and implementation plan	NT Government	<p>Key Actions:</p> <ul style="list-style-type: none"> • Reduced registration and stamp duty fees for EVs 	https://dipl.nt.gov.au/strategies/electric-vehicle	

		<ul style="list-style-type: none"> • EV Charger grant scheme • Facilitating the installation of more EV charging stations • Supporting local innovation in EV technology <ul style="list-style-type: none"> • Skills development for EV servicing and EV charging infrastructure installation • Promoting information on EV charging locations • Increasing the number of EVs in the NT Government fleet 	https://dipl.nt.gov.au/_data/assets/pdf_file/0007/742759/electric-vehicle-discussion-paper-2019.pdf https://dipl.nt.gov.au/_data/assets/pdf_file/0007/1027483/electric-vehicle-strategy-implementation-plan.PDF	
Registration and stamp duty concessions for electric vehicles	NT Government	Registration and stamp duty concessions	https://nt.gov.au/driving/rego/fees/registration-fees https://nt.gov.au/driving/rego/getting-an-nt-registration/get-electric-vehicle-registration-and-stamp-duty-concessions	From 1 July 2022
TAS				
Supporting Electric Vehicle Uptake—Fact Sheet	Tasmanian Government		https://www.dpac.tas.gov.au/divisions/climatechange/Climate_Change_Priorities/reducing_emissions/transport/supporting_electric_vehicle_update_-_fact_sheet	
Smarter Fleets	Tasmanian Government	<ul style="list-style-type: none"> • Heavy vehicles • EVs in local governments • EVs in the Tasmanian Government 	https://www.dpac.tas.gov.au/divisions/climatechange/Climate_Change_Priorities/reducing_emissions/transport/smarter_fleets	
Charge Smart Grants Program	Tasmanian Government	Supports the installation of charging stations	https://www.dpac.tas.gov.au/divisions/climatechange/Climate_Change_Priorities/reducing_emissions/transport/chargesmart_grants	2021 (Stage 2) grants program is complete

Climate Action 21: Tasmania's Climate Change Action Plan 2017–2021	Tasmanian Government	<p>Outlines six priorities</p> <ol style="list-style-type: none"> 1. understanding Tasmania's future climate 2. advancing our renewable energy capability 3. reducing our transport emissions 4. growing a climate ready economy 5. building climate resilience 6. supporting community action 	https://www.dpac.tas.gov.au/divisions/archived-climatechange/tasmanias_climate_change_action_plan_20172021	
ACT				
EV Ready Developments (Urbis)	ACT Government	<p>The ACT Planning System Review and Reform Project seeks to create a clear, easy to use planning system that delivers improved spatial and built outcomes across the Territory.</p> <p>Consultations conducted in 2022</p>	https://www.planning.act.gov.au/planning-our-city/act-planning-system-review-and-reform/resources/ev-ready-developments-urbis	
The ACT's transition to zero emissions vehicles: Action Plan 2018–21	ACT Government	Presents future actions	https://www.environment.act.gov.au/__data/assets/pdf_file/0012/1188498/2018-21-ACTs-transition-to-zero-emissions-vehicles-Action-Plan-ACCESS.pdf	
The ACT's transition to zero emissions vehicles: Action Plan 2018–21	ACT Government	<p>Transition includes:</p> <ul style="list-style-type: none"> • Supporting new and innovative businesses in the ZEV sector 	https://www.climatechoices.act.gov.au/transport-and-travel/cars-and-vehicles/the-future-of-zevs	

		<ul style="list-style-type: none"> • Working with local and state governments to install charging stations on major routes to and from the ACT • Changing road rules and the <i>Parking and Vehicle Access General Code</i> to promote ZEV uptake • Leasing ZEVs for ACT Government fleet passenger vehicles • Trialling financial incentives to encourage the uptake of ZEVs and electric bikes • Roll out of charging stations 		
EV-ready information for industry	ACT Government	The installation of EV-ready infrastructure in new and existing buildings is currently not mandatory in the ACT. However, installation of EV-ready infrastructure will be mandatory in new developments (multi-unit residential and townhouses) when the new planning system is introduced in the ACT in 2023	https://www.planning.act.gov.au/planning-our-city/act-planning-system-review-and-reform/resources/ev-ready-information-for-industry https://www.planning.act.gov.au/__data/assets/pdf_file/0008/2021597/EV-Ready-information-for-Industry.pdf	<p>Provides a good outline of multi-unit buildings and best practice to make new residential and commercial buildings EV ready</p> <p>Outlines some of the challenges with existing properties</p>
Sustainable Household Scheme	ACT Government	Zero interest loans	https://www.climatechoices.act.gov.au/policy-programs/sustainable-household-scheme	
Electric vehicle charging outlook for the ACT Guidance for Industry	ACT Government	<p>Policies to encourage EV uptake include:</p> <ul style="list-style-type: none"> • Two years free registration • Stamp duty waiver 	https://www.environment.act.gov.au/__data/assets/pdf_file/0007/1914802/electric-vehicle-charging-outlook-for-the-act-industry-guidance-2021.pdf	

		<ul style="list-style-type: none"> access to no-interest loans up to \$15,000 for ZEVs and charging equipment Transitioning the government fleet to ZEVs, starting with 100% of new leases from 2021 to be ZEVs, where fit for purpose 		
Australian Government				
Future Fuels and Vehicles Strategy	Federal Government	<p>Five Priorities:</p> <ol style="list-style-type: none"> Ensuring EV charging and hydrogen refuelling infrastructure is installed where it is needed Fleet conversions Increasing consumer confidence Integrating battery EVs to the grid Supporting Australian innovation and manufacturing 	https://www.industry.gov.au/data-and-publications/future-fuels-and-vehicles-strategy	Published before May 2022
Future fuels and vehicles strategy: powering choice	Federal Government	Consultation Report November 2021	https://www.industry.gov.au/sites/default/files/November%202021/document/future-fuels-and-vehicles-strategy.pdf	
Integrated System Plan 2022	AEMO	Whole-of-system plan covering the NEM	https://aemo.com.au/en/energy-systems/major-publications/integrated-system-plan-isp/2022-integrated-system-plan-isp	
Wholesale Electricity Market (WEM) for the Southwest	AEMO	Structures and processes for the WEM were developed by Energy Policy WA. Details are in the 2012 summary.	https://aemo.com.au/en/energy-systems/electricity/wholesale-electricity-market-wem/about-the-wholesale-electricity-market-wa-wem	

Interconnected System of WA (SWIS)			https://aemo.com.au/-/media/files/electricity/wem/wem-design-summary-v1-4-24-october-2012.pdf	
Retail exemptions	AER	<p>Retail exemptions examples:</p> <ul style="list-style-type: none"> • Retirement villages where an owner or manager buys electricity from an authorised retailer, then ‘on-sells’ it to residents • Caravan parks (or manufactured homes parks) where an owner or manager buys electricity from an authorised retailer, then ‘on-sells’ it to residents • Bodies corporate/owners’ corporations who buy electricity from an authorised retailer, then ‘on-sell’ it to tenants or residents • Persons selling energy at no profit or as a community service 	https://www.aer.gov.au/retail-markets/retail-exemptions	These exempt parties are usually found defined in the respective States’ Owners Corporations Acts (may also referred to as Body Corporate or other depending on each state’s 62 legislation), and also in the respective <i>Residential Tenancies Acts</i> .

Appendix III: Law and regulation table

Law/Regulation	Cwlth/ State/ National	Purpose	Link	Comment
South Australia				
National Electricity (South Australia) Act 1996	SA	This Act defines the national electricity law (NEL) within its schedule. Sections 6 of the <i>National Electricity (SA) Act 1996</i> applies to SA, however, s5 confirms that its application applies to the <i>operations</i> of the national electricity system (which include interconnected states and territories beyond SA borders).	https://www.legislation.sa.gov.au/lz/path=%2FC%2FA%2FNATIONAL%2oELECTRICITY%2o(SOUTH%2oAUSTRALIA)%2oACT%2o1996	

		It “establishes the governance and enforcement framework and key obligations surrounding the national electricity market and the regulation of access to electricity networks.” ¹¹⁰		
National Electricity (South Australia) Regulations	SA	The NEL is supported by these regulations.	https://www.legislation.sa.gov.au/lz/path=%2FC%2FR%2FNational%2oElectricity%2o(South%2oAustralia)%2oRegulations	
National Electricity (South Australia) (Local Provisions) Regulations 2019	SA		https://www.legislation.sa.gov.au/lz/path=%2FC%2FR%2FNational%2oElectricity%2o(South%2oAustralia)%2o(Local%2oProvisions)%2oRegulations%2o2019	
National Energy Retail Law (South Australia) Act 2011	SA	Regulates the supply and sale of energy to customers. The provisions apply to the relationship between distributors and consumers. “The objective of this law is to promote efficient investment in, and efficient operation and use of, energy services for the long-term interests of consumers of	https://www.legislation.sa.gov.au/lz/path=%2FC%2FA%2FNATIONAL%2oENERGY%2oRETAIL%2oLAW%2o(SOUTH%2oAUSTRALIA)%2oACT%2o2011	

¹¹⁰ Australian Government—Department of Climate Change, Energy, the Environment and Water. (2022). Energy market legislation. <https://www.energy.gov.au/government-priorities/energy-markets/energy-market-legislation>

		energy with respect to price, quality, safety, reliability and security of supply of energy.” ¹¹¹		
National Energy Retail Regulations	SA	Regulates matters including: business and household consumption thresholds to determine the status of large and small customers feed-in arrangements Transitional provisions for retailers and exempt sellers	https://www.legislation.sa.gov.au/lz/path=%2FC%2FR%2FNational%2oEnergy%2oRetail%2oRegulations	Cross references to participating state and territories’ legislation
Strata Titles Act 1988	SA		https://www.legislation.sa.gov.au/_legislation/lz/c/a/strata%2otitles%2oact%2o1988/current/1988.13.auth.pdf	
Strata Titles Regulations 2018	SA		https://www.legislation.sa.gov.au/_legislation/lz/c/r/strata%2otitles%2oregulations%2o2018/current/2018.193.a.uth.pdf	
Victoria				
National Electricity (Victoria) Act 2005 Act	Vic	Victorian Government assented mirror legislation to the NEL (SA)	https://content.legislation.vic.gov.au/sites/default/files/2022-05/05-8aa033%2oauthorised.pdf	Replaces the 1997 version

¹¹¹ *National Energy Retail Law (South Australia) Act 2011*— Schedule s13–National Energy Retail Objective.
[https://www.legislation.sa.gov.au/lz/path=%2FC%2FA%2FNATIONAL%2oENERGY%2oRETAIL%2oLAW%2o\(SOUTH%2oAUSTRALIA\)%2oACT%2o2011](https://www.legislation.sa.gov.au/lz/path=%2FC%2FA%2FNATIONAL%2oENERGY%2oRETAIL%2oLAW%2o(SOUTH%2oAUSTRALIA)%2oACT%2o2011)

Electricity Safety Act 1998	Vic	“The purpose of this Act is to make further provision relating to—(a) the safety of electricity supply and use, (b) the reliability and security of electricity supply, and (c) the efficiency of electrical equipment.”	https://content.legislation.vic.gov.au/sites/default/files/2020-12/98-25aa081%20authorised.pdf	If sustainability items are added to buildings or the grid as a load or generator, they must be safe.
Energy Safe Victoria Act 2005	Vic	Establishment of the Energy Safe Victoria Commission	https://content.legislation.vic.gov.au/sites/default/files/2020-12/05-39aa014%20authorised.pdf	
Electricity Industry Act 2000	Vic	Licensing permissions: a participant that generates, transmits, distributes, supplies or sells electricity needs to obtain a licence from the Essential Services Commission of Victoria or obtain a licence exemption.	https://content.legislation.vic.gov.au/sites/default/files/2022-05/00-68aa095%20authorised.pdf	
State Electricity Commission Act 1958	Vic		https://content.legislation.vic.gov.au/sites/default/files/2020-04/58-6377aa105%20authorised.pdf	
Victorian Energy Efficiency Target Act 2007	Vic	Promotes the reduction of greenhouse gas emissions by establishing the VEET scheme	https://content.legislation.vic.gov.au/sites/default/files/2021-12/07-70aa018%20authorised.PDF	
Victorian Renewable Energy Act 2006	Vic	Promotes the development of renewable energy generation through the establishment of a scheme	https://content.legislation.vic.gov.au/sites/default/files/2021-12/06-72aa013%20authorised.pdf	

Electricity Industry (Residual Provisions) Act 1993	Vic	Restructuring of the electricity supply industry	https://content.legislation.vic.gov.au/sites/default/files/e3ece014-ecf7-3327-960f-1f660d02521e_93-130aa071%20authorised.pdf	
Essential Services Commission Act 2001	Vic	Allows the Commission to fulfil regulatory and advisory functions that provide incentives for dynamic, productive, and allocative efficiency and promotes the long-term interests of Victorian consumers.	https://content.legislation.vic.gov.au/sites/default/files/2022-06/01-62aa061%20authorised.pdf	
Essential Services Act 1958	Vic	<p>Defines the essential services, including transport, light, and power</p> <p>Provision of transport to the public includes taxis, buses etc.</p> <p>Note: rail-bound vehicles are already largely electrified and connected to the electricity grid supply via transformers. Transport system expanded incrementally.</p>	https://content.legislation.vic.gov.au/sites/default/files/dce91bb1-856a-3774-ba0b-50a0fe8d7c39_58-6244aa054%20authorised.pdf	EVs are primarily a mobility device and a load that plug into the electricity system to source power.
National Electricity (Victoria) Act 2005 – VNI SIPS MINISTERIAL ORDER	Vic	This order empowers AEMO to perform the procurement process for the System Integrity Protection Scheme to increase the capacity of the Victoria–New South Wales Interconnector, the 330 kV transmission lines connecting Murray to Dederang and Dederang to South Morang, together with the transmission plant of those lines.	https://www.energy.vic.gov.au/_data/assets/pdf_file/0025/465028/VNI-SIPS-Ministerial-Order-special-gazette-2020-S238.pdf	

National Electricity (Victoria) Act 2005 - SECOND VNI SIPS MINISTERIAL ORDER	Vic	This order allows AEMO to enter into a VNI System Integrity Protection Scheme (SIPS) agreement with the SIPS service provider and related financing parties under a tripartite agreement. It allows the recovery of costs through Transmission Use of System (TUoS) charges.	https://www.energy.vic.gov.au/_data/assets/pdf_file/0034/495079/Second-VNI-Ministerial-Order.pdf	
Electricity Safety (Management) Regulations 2019	Vic	Management of electrical safety on complex electrical installations amongst other items, including where there are no published electrical standards. ¹¹²	https://content.legislation.vic.gov.au/sites/default/files/85883697-8e7e-3265-a406-5229ce8c1ebd_19-114sra001%20authorised.pdf	
Electricity Safety (Equipment Safety Scheme) Regulations 2019	Vic	Includes the prescription of standards for electrical equipment and in-scope electrical equipment	https://content.legislation.vic.gov.au/sites/default/files/a099f151-cf4f-35d2-90c4-96d9ofda8b5a_19-17sra001%20authorised.pdf	
Transport (Compliance and Miscellaneous) Act 1983	Vic	Includes licensing of certain vehicles and drivers, and accreditation of passenger transport companies.	https://content.legislation.vic.gov.au/sites/default/files/2020-04/83-9921aa216%20authorised.pdf	
Transport Integration Act 2010	Vic	Framework for an integrated and sustainable transport system	https://content.legislation.vic.gov.au/sites/default/files/2022-06/10-6aa084%20authorised.pdf	

¹¹² Electricity Safety (Management) Regulations 2019 (Vic) 2019 Division 2. <https://www.legislation.vic.gov.au/in-force/statutory-rules/electricity-safety-management-regulations-2019/001>

Zero and Low Emission Vehicle Distance based Charge Act 2021	Vic	Requirement for registered operators of zero and low emission vehicles to pay a charge for use of the vehicles on certain roads	https://content.legislation.vic.gov.au/sites/default/files/2021-06/21-018aa%20authorised.pdf	
Road Safety Act 1986	Vic	Includes vehicle defects, and automated vehicle provisions	https://content.legislation.vic.gov.au/sites/default/files/2022-07/86-127aa216%20authorised.pdf	
Subdivision Act 1988	Vic	The purposes of this Act are to—“(a) set out the procedure for the subdivision and consolidation of land, including buildings and airspace, and for the creation, variation or removal of easements or restrictions; and (b) regulate the management of and dealings with common property and the constitution and operation of owners corporations.”	https://content.legislation.vic.gov.au/sites/default/files/2021-12/88-53aa080%20authorised.pdf	Allows for the creation of an OC; regulates alterations to subdivisions
Owners Corporations Act 2006	Vic	<i>Sustainability Items</i> ¹¹³ are a new addition to the OC Act and refer to anything that eliminates or reduces a reliance on non-sustainable energy sources. Defines the ‘tiers’ of multi-unit dwellings, and including retirement villages	https://content.legislation.vic.gov.au/sites/default/files/2021-12/06-69aa019%20authorised.pdf	Example – Each state has its own legislation Central to the success of adding in <i>Sustainability Items</i> . Much of the OC Act inhibits the majority of multi-unit building

¹¹³ *Owners Corporations Act 2006 (Vic)* s138B (4). https://classic.austlii.edu.au/au/legis/vic/consol_act/oca2006260/s138b.html

				and lot owners from benefitting.
Building Act 1993	Vic	Regulates building work and building standards	https://content.legislation.vic.gov.au/sites/default/files/2021-10/93-126aa133%20authorised.pdf	Residential construction, standards, practices and approvals are currently under scrutiny across Australia.
Domestic Building Contracts Act 1995	Vic	Regulates residential building contracts Defines domestic building work Includes refurbishments, such as adding <i>Sustainability Items</i> to buildings Contracts also apply to occupied buildings	https://content.legislation.vic.gov.au/sites/default/files/2021-10/95-91aa088%20authorised.pdf	Central to the complexity of retrofitting existing building stock to include PV solar, storage and charging stations
Planning and Environment Act 1987 (Vic)	Vic	Principal Act to establish a framework for planning use, development and protection of land in Victoria in the present and long-term interests of all Victorians. Includes affordable housing measures, and interfaces with the <i>Transport Integration Act 2010</i> .	https://content.legislation.vic.gov.au/sites/default/files/2022-02/87-45aa153%20authorised.pdf	Affordable housing is usually a multi-unit style property type.
Planning and Environment (Planning Schemes) Act 1996 (Vic)	Vic	Provides for the preparation of municipal strategic statements and the making of Victoria Planning Provisions, procedure for the issue of planning permits	https://content.legislation.vic.gov.au/sites/default/files/2021-10/96-531a036-a4ed-317e-92e3-e40a9643f9a2_96-77aa005%20authorised.pdf	

Victoria Planning Provisions (VPP)	Vic	The VPP aim to provide a clear framework to assist decision making with respect to state, regional, local and community expectation about land use whilst implementing state policies.	https://planning-schemes.app.planning.vic.gov.au/Victoria%20Planning%20Provisions/ordinance?_ga=2.146137270.384030307.1658464816-494640648.1658464816	
New South Wales				
National Electricity (New South Wales) Act 1997 No 20	NSW	This Act, along with the NEL (NSW) and National Electricity Regulations (NSW), binds NSW to the NEL (SA); mirror legislation	https://legacy.legislation.nsw.gov.au/-/pdf/view/act/1997/20/whole	
National Electricity (NSW) Law No 20a	NSW	NEL (NSW)	https://legacy.legislation.nsw.gov.au/-/pdf/view/act/1997/20a/whole?download=false	
National Electricity (New South Wales) (Savings and Transitional) Regulation 1998	NSW	Transition to the NEM, and protected contracts	https://legacy.legislation.nsw.gov.au/-/pdf/view/regulation/1998/672/whole	
Electricity Supply Act 1995 No 94	NSW	The purpose of the Act is: a. To promote the efficient and environmentally responsible production and use of electricity and to deliver a safe and reliable supply of electricity, and Note— Customer choice and rights in relation to electricity connections and electricity supply are provided for by the National Energy Retail Law (NSW).	https://legacy.legislation.nsw.gov.au/-/pdf/view/act/1995/94/whole	

		<p>b. To confer on network operators such powers as are necessary to enable them to construct, operate, repair and maintain their electricity works</p> <p>c. (Repealed)</p> <p>d. To promote and encourage the safety of persons and property in relation to the generation, transmission, distribution and use of electricity, and</p> <p>e. To ensure that any significant disruption to the supply of electricity in an emergency is managed effectively.</p>		
National Energy Retail Law (NSW) No 37a of 2012		<p>Application is defined as</p> <p>“(a) the sale and supply of electricity or gas or both to customers; and (b) a retailer to the extent the retailer sells electricity or gas or both; and</p> <p>(c) a distributor to the extent the distributor supplies electricity or gas or both.”</p>	https://legacy.legislation.nsw.gov.au/-/pdf/view/act/2012/37a/whole	
National Energy Retail Law (Adoption) Act 2012 No 37	NSW		https://legacy.legislation.nsw.gov.au/-/pdf/view/act/2012/37/whole	

National Energy Retail Law (Adoption) Regulation 2020	NSW		https://legacy.legislation.nsw.gov.au/-/pdf/view/regulation/2020/511/whole	
Electricity Supply (General) Regulation 2014	NSW	Service standards	https://legacy.legislation.nsw.gov.au/-/pdf/view/regulation/2014/523/whole	
Electricity Supply (Safety and Network Management) Regulation 2014	NSW	<p>This regulation defines standards and states that</p> <p>“The primary objective of safety management systems is to assist network operators to comply with Clause 5 and, in particular, to support: (a) the safety of members of the public, and (b) the safety of persons working on networks, and (c) the protection of property (whether or not belonging to a network operator), and (d) the management of safety risks arising from the protection of the environment (for example, preventing bush fires that may be ignited by network assets), and (e) the management of safety risks arising from loss of electricity supply.”</p>	https://legacy.legislation.nsw.gov.au/-/pdf/view/regulation/2014/524/whole	
Gas and Electricity (Consumer Safety) Act 2017 No 15	NSW	Consumer safety	https://legacy.legislation.nsw.gov.au/-/pdf/view/act/2017/15/whole	

Gas and Electricity (Consumer Safety) Regulation 2018	NSW	Includes the reference to some standards, and outlines appliance certification, and installations	https://legacy.legislation.nsw.gov.au/-/pdf/view/regulation/2018/501/whole	
Home Building Act 1989 No 147	NSW	Applies to an existing or new dwelling	https://legacy.legislation.nsw.gov.au/-/pdf/view/act/1989/147/whole?download=false	
Strata Schemes Management Act 2015 No 50	NSW	Regulates multi-unit properties	https://legacy.legislation.nsw.gov.au/-/pdf/view/act/2015/50/whole	
Queensland				
Electricity—National Scheme (Queensland) Act 1997	QLD	Applies the NEL to QLD	https://www.legislation.qld.gov.au/view/html/inforce/current/act-1997-027	
Electricity Act 1994	QLD	<p>The <i>Electricity Act</i> includes the regulations for the electricity industry and electricity use. Licensing of electricity industry participants is covered, as is monitoring of licence compliance. It is used to approve electricity prices for standing offer customers. It also regulates the administration of electricity restrictions and electricity rationing procedures.</p> <p>This Act enables owners, occupiers or users of a premises to become an on-supplier who can supply electricity to the occupants of the premises (the receivers).</p>	https://www.legislation.qld.gov.au/view/html/inforce/current/act-1994-064	On-suppliers might be shopping centre owners, caravan park owners, owners of blocks of flats and bodies corporate associated with blocks of residential or commercial units; Body Corporate and other Laws permitting.

Electricity Regulation 2006	QLD	This is read in conjunction with the Electricity Act 1994.	https://www.legislation.qld.gov.au/view/html/inforce/current/sl-2006-0200	
Electricity Distribution Network Code	QLD	Outlines rules for retailers and distributors in Queensland Administered by the Queensland Competition Authority	https://www.qca.org.au/project/retailers-and-distributors/electricity-distribution-network-code/ https://www.qca.org.au/	
Electrical Safety Act 2002	QLD	This act establishes a legislative framework for: Preventing persons from being killed or injured by electricity Preventing property from being destroyed or damaged by electricity	https://www.legislation.qld.gov.au/view/html/inforce/current/act-2002-042	
Electrical Safety (Codes of Practice) Notice 2013	QLD	This notice allows for, and lists, relevant codes of practice.	https://www.legislation.qld.gov.au/view/html/inforce/current/sl-2013-0276	
Electrical Safety Regulation 2013	QLD	The purposes are defined to be:	https://www.legislation.qld.gov.au/view/html/inforce/current/sl-2013-0213	

		<p>“(a) ensuring the electrical safety of licensed electrical workers, other workers, licensed electrical contractors, consumers and the general public</p> <p>(b) enhancing consumer protection for electrical work</p> <p>(c) stopping cathodic protection systems from damaging or interfering with the property of others</p> <p>(d) ensuring a safe supply of electricity</p> <p>(e) ensuring electrical equipment hired or sold is electrically safe.”</p>		
Western Australia				
Electricity Industry Act 2004	WA	The principal Act for the electricity industry	https://www.legislation.wa.gov.au/legislation/statutes.nsf/law_a7017.html	
Electricity Industry Act 2004 Subsidiary legislation as made under this Act	WA	<p>Subsidiary legislation includes:</p> <p>Standalone power systems</p> <p>Obligation to connect</p> <p>Customer contracts</p> <p>License conditions</p> <p>Metering customer transfer</p> <p>Network quality and reliability of supply</p>	https://www.legislation.wa.gov.au/legislation/statutes.nsf/law_a7017_subsidary.html	

Electricity Industry (Licence Conditions) Regulations 2005	WA	Applies to generation and transmission	https://www.legislation.wa.gov.au/legislation/statutes.nsf/law_s37159.html	
Electricity Industry (Wholesale Electricity Market) Regulations 2004	WA		https://www.legislation.wa.gov.au/legislation/statutes.nsf/main_mrtitle_1353_homepage.html	
Northern Territory				
National Electricity (Northern Territory) (National Uniform Legislation) Act 2015	NT	NT electricity law	https://legislation.nt.gov.au/en/Legislation/NATIONAL-ELECTRICITY-NORTHERN-TERRITORY-NATIONAL-UNIFORM-LEGISLATION-ACT-2015	
National Electricity (Northern Territory) (National Uniform Legislation) (Modification) Regulations 2016	NT	NT electricity regulations	https://legislation.nt.gov.au/en/Legislation/NATIONAL-ELECTRICITY-NORTHERN-TERRITORY-NATIONAL-UNIFORM-LEGISLATION-MODIFICATION-REGULATIONS-2016	
National Electricity Rules as in force in the Northern Territory Version 88	NT	NT electricity rules	https://energy-rules.aemc.gov.au/ntner/397	Reflect NER v183.

ACT				
Electricity (National Scheme) Act 1997	ACT	Enables the mirror legislation to apply	https://www.legislation.act.gov.au/a/1997-79/default.asp	
National Energy Retail Law (ACT) Act 2012	ACT	NEL mirror legislation	https://www.legislation.act.gov.au/a/2012-31/default.asp	
Electricity (National Scheme) Act 1997	ACT	Enables the mirror legislation to apply	https://www.legislation.act.gov.au/a/1997-79/default.asp	
Utilities Act	ACT	Licensing	https://www.legislation.act.gov.au/a/2000-65/default.asp	
Electricity Feed-in (Renewable Energy Premium) Act 2008	ACT		https://www.legislation.act.gov.au/a/2008-21/default.asp	
Tasmania				
Electricity - National Scheme (Tasmania) Act 1999	TAS	Enables the NEL (Tasmania)	https://www.legislation.tas.gov.au/view/whole/html/inforce/current/act-1999-028	
National Electricity (Tasmania) Law	TAS	NEL (Tasmania)—mirror legislation with modifications to the NEL (SA)	https://www.legislation.tas.gov.au/view/whole/html/inforce/2005-05-29/act-1999-28A	

Commonwealth				
Australian Energy Market Agreement (AEMA)	CoAG Energy Council (ENCRC and EMM)	<p>“The Energy National Cabinet Reform Committee (ENCRC) and the Energy Ministers’ Meeting (EMM) are ministerial forums for the Commonwealth, Australian states and territories, and New Zealand to work together on priority issues of national significance and key reforms in the energy sector.”¹¹⁴</p> <p>The agreement allowed for the establishment of market institutions and for each state and territory to enact better aligned legislation, mirror legislation.</p>	https://www.energy.gov.au/government-priorities/energy-ministers/energy-ministers-publications/australian-energy-market-agreement-amended-december-2013	Amended: December 2013.
National Electricity Rules	AEMC	<p>The Rules govern the operation of the NEM and are made to ensure a coordinated approach by NEM participants.</p> <p>The Rules are required by law to follow the <i>National Electricity Objective (NEO)</i>¹¹⁵ as defined in Schedule—NEL.</p> <p>An explainer on how AEMC applies the NEO when considering and making Rule changes.</p>	https://energy-rules.aemc.gov.au/ner/396 https://www.aemc.gov.au/sites/default/files/2019-07/Applying%20the%20energy%20market%20objectives_1.pdf	Living document that follows a strict consultative change process.

¹¹⁴ Australian Government Department of Climate Change, Energy, the Environment and Water. (2022). *Energy and Climate change Ministerial Council*. <https://www.energy.gov.au/government-priorities/energy-and-climate-change-ministerial-council>

¹¹⁵ *National Electricity (South Australia) Act 1996* Schedule 57. [https://www.legislation.sa.gov.au/lz/path=%2FC%2FA%2FNATIONAL%20ELECTRICITY%20\(SOUTH%20AUSTRALIA\)%20ACT%201996](https://www.legislation.sa.gov.au/lz/path=%2FC%2FA%2FNATIONAL%20ELECTRICITY%20(SOUTH%20AUSTRALIA)%20ACT%201996)

National Energy Customer Framework (NECF)	AEMC	<p>Describes the instruments that are used to regulate the sale and supply of electricity (and gas) to retail customers:</p> <p>National Energy Retail Law (Retail Law)—Refer to SA</p> <p>National Energy Retail Rules (Retail Rules)—Refer to AEMC</p> <p>National Energy Retail Regulations (Regulations)—Refer to SA</p>	<p>https://www.aemc.gov.au/regulation/energy-rules/national-energy-retail-rules/regulation</p> <p>https://www.aemc.gov.au/regulation/energy-rules/guide-application-necf</p>	
National Energy Retail Rules	AEMC		https://www.aemc.gov.au/regulation/energy-rules/national-energy-retail-rules/rules-made	

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