Battery Storage and Grid Integration Program
An initiative of The Australian National University

REVS

The A to Z of V2G

A comprehensive analysis of vehicle-to-grid technology worldwide

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Executive Summary

A transport evolution is happening. The adoption of electric vehicles (EVs) is accelerating in many parts of the world, driven by their lower environmental impact and running costs compared to internal combustion engine (ICE) vehicles, as well as by consumer preferences. EVs depend on electricity grids for charging their batteries, and as a result a “sector coupling” between automotive transport and electricity systems is underway, creating new and complex interdependencies.

Collectively, the relatively high power requirements of EV charging will change societal electricity consumption patterns and if not managed well will place significant strain on the grid. However, the large storage capacity of EV batteries presents an opportunity for better grid management, especially considering the long periods of time that most vehicles spend parked. Vehicle to grid (V2G) is a new technology that promises to connect these dots.

V2G is the concept of discharging an EV battery in order to serve a secondary purpose. It fits within a broader landscape of charging technologies as shown in Figure 1. It can be used to manage energy within a home (**V2H**), a building or microgrid (**V2B**), the grid (**V2G**), or many other purposes (**V2X**). In this report we use the term V2H to describe local energy use cases, and V2G where the discharge capability is providing wider system services.

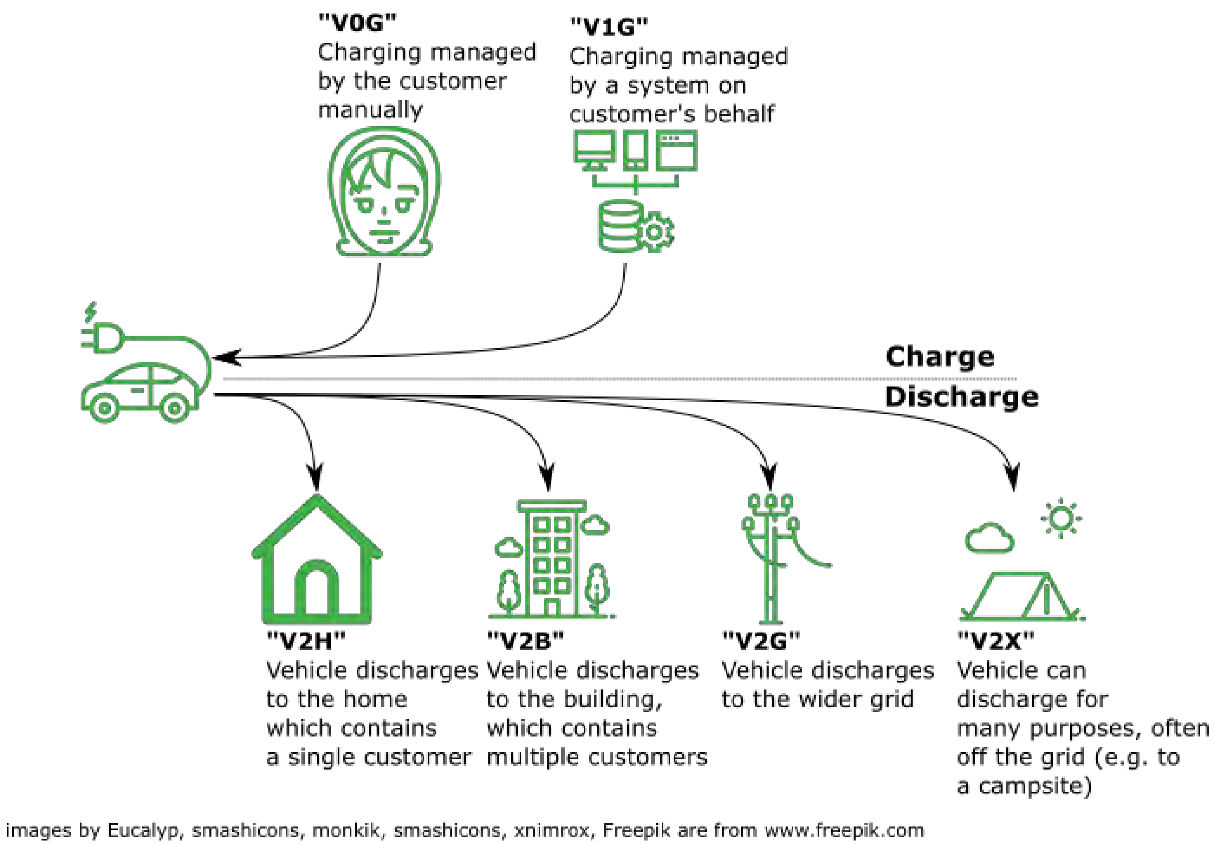

Figure 1: Smart charging landscape

EVs represent a sector coupling of the transport and energy sectors. Primarily transport devices, they require electricity for their fuel. Studies have shown EVs could increase peak demand by around one quarter, if unmanaged. With V2G however, a single asset (a car) can provide both energy and transport services. Our review describes many of the energy services that EVs could provide and emphasises the real benefits they could deliver. Users, energy market participants, and the general public all stand to benefit from V2G.

Users own and ultimately control the V2G operation of their vehicle. Much like a home energy storage system, V2G can reduce energy bills by managing rooftop PV and grid demand. Similarly, many V2G chargers can operate while disconnected from the main grid in backup or islanded configuration. This is enhanced by the mobility of EVs: people can charge at functional public chargers and transport that energy back to their home. As the owners of the energy storage system, EV owners receive a share of the wider benefits of V2G as a financial reward. Further detail on this is in section 3.1.

There are numerous V2G use cases for the **electricity system**. The REVS project (see info box at the end of the executive summary for details) is demonstrating one of them: frequency control. Frequency control is of particular interest as it provides necessary services to the grid while only requiring occasional use of the vehicle's battery. Other use cases such as energy price arbitrage and congestion management can unlock significant value from the battery in line with terms agreed with the EV owner. The benefits of these services accrue to both vehicle owners (as financial rewards) and all electricity users (as lower wholesale energy prices). These are further discussed in 3.2.

Beyond the electricity system V2G can benefit **society** as a whole. As mentioned, V2G can reduce electricity prices. Their cheap, flexible storage supports renewable generation integration, a necessary element of the clean energy transition. Similarly, by reducing the total cost of ownership of EVs, V2G can increase uptake of EVs, creating additional environmental benefits. Engagement in the electricity market via V2G may help reverse the legacy trust deficit many people have in the energy system. These benefits are further discussed in 3.3.

Even with all these benefits, V2G remains a niche product. It has not seen wide uptake, even in regions with high EV adoption. There are a number of reasons for this, spanning economic, financial, and customer experience. The most fundamental may stem from the sector coupling itself. Automotive transport and electricity have evolved as two largely separate systems, as shown in Figure 2. Each has a set of norms, practices, relationships, user needs, regulatory requirements, and infrastructure that must evolve to create shared narratives around V2G that will encourage and facilitate adoption of V2G.

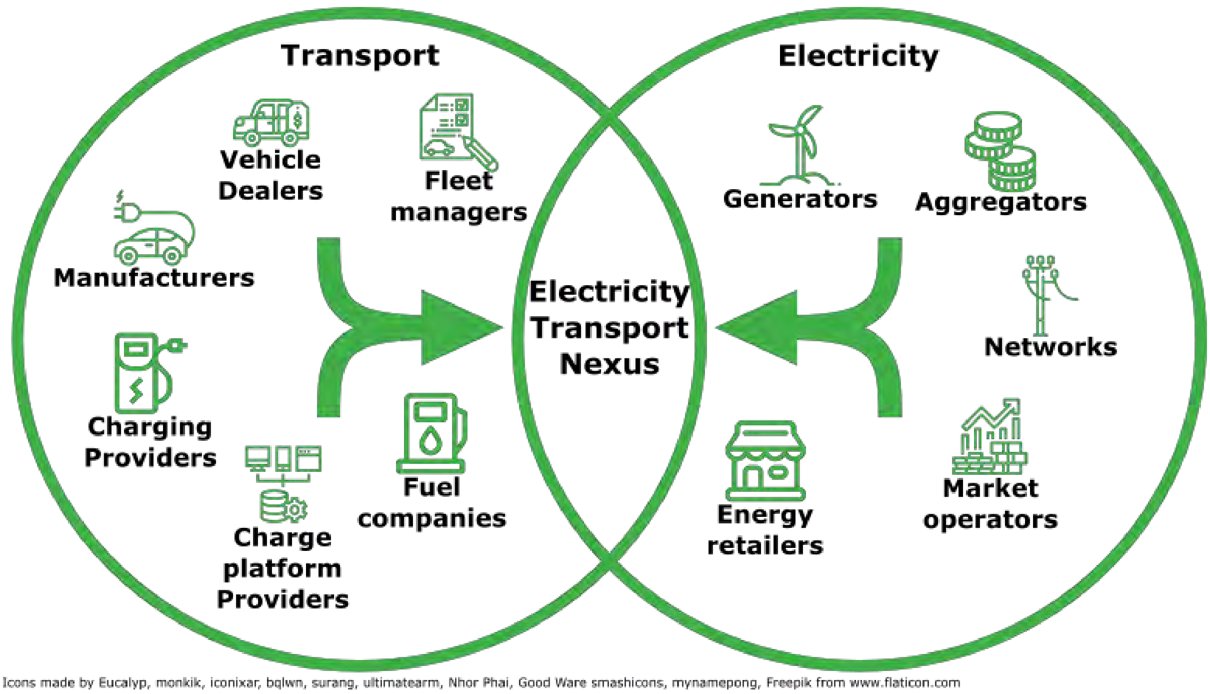

Figure 2: Electricity transport sector coupling

V2G uptake is not guaranteed, nor would it necessarily be a straight or smooth path to broad adoption. There are challenges that need to be addressed along the way. Some of these are common to other distributed energy resources: network congestion for example may be exacerbated by EVs and V2G. The My Electric Avenue project in the UK indicated that unmanaged charging could cause 32% of distribution transformers in the UK to require replacement when 40-70% of customers have EVs. V2G may exacerbate this as a V2G-enabled EV battery is both a large generator and a large load, particularly on a domestic connection.

Existing barriers to demand response equally apply to V2G. Standards often are not designed for distributed energy resources, and multiple value streams are difficult to stack. It can be difficult to determine how much value each charger can realise. This is discussed further in 4.2

Prospective EV owners are largely unaware V2G is possible, and even then, there are few compelling narratives to encourage uptake. V2G can be perceived as a threat to mobility and its symbolic meaning for people. Similarly, as a high value asset people may be reticent to allow additional wear on their vehicle's battery. This is discussed further in 4.1.

V2G is currently expensive. It is yet to be determined whether there is sufficient benefit in V2G to justify its expense or when it might become economically viable. Costs come from not only the charger, but its efficiency, and additional battery wear, discussed in 4.1 and 4.2.

Trials are essential for mapping out the viability of V2G. They demonstrate use cases, map barriers, and explores narratives around V2G. Beyond trials, however, V2G requires a path to the mainstream in order for its benefits to be realised. The multi-level perspective, a well-known theory of socio-technical change, emphasises the need focus on the co-evolution of technology and society. This includes not only devices, entrepreneurs and users but the cultural, infrastructural, financial, regulatory, political and other networks that make up the whole picture.

The REVS project has a broad focus, as demonstrated in this document. But as a small scale trial it will not embed V2G. It is up to the industry – participants and beyond – to build upon the work of REVS and embed V2G in their practices. Our recommendations both in this report and the final report aim to bring governments and industry on this journey.

Recommendations

We have reviewed the V2G literature and trial experiences around the world, presented as benefits, challenges, and enablers. Based on the existing body of knowledge we can recommend actions that will enable smoother uptake of V2G. These are written for Australia but are broadly applicable. Recommendations fall into four themes: standards and rules, customer value proposition, open value transfer, and fostering an industry. Within each theme we recommend actions falling into three groups:

- Actions for **immediate** implementation
- Actions that are being **explored during the REVS trial**, for which we will provide specific next steps in our final report
- Actions that we expect will be required in the **future** but whose precise form requires further work to define.

Standards and rules
V2G will see the most uptake when there are clear standards and rules around its usage, spanning charging standards at the vehicle end, and system standards and rules at the grid end. As a form of demand response, V2G has much in common with distributed storage, solar, and other forms of demand response.

At this nascent stage of V2G it is important to “right size” rules. Rules should seek to strike the appropriate balance between allowing V2G to deliver value, and managing risks.

Table 1 Standards and Rules recommendations

ID	Action type	Who needs to act?	What do they need to do?
1.	Immediate	Standards bodies	Ensure grid connection standards (e.g AS/NZS 4777) are not a barrier to V2G. Standards must: • Recognise V2G and allow for its specific use cases • Coordinate with vehicle and international standards to avoid conflict and harmonise where possible.

ID	Action type	Who needs to act?	What do they need to do?
2.	Immediate	DNSPs	DNSPs are central to enabling value from V2G. DNSPs should: • Implement dynamic connection point constraint technologies to replace today's restrictive constraints and enable easier market participation of V2G. In the future this may also require constraint forecasting to enable easier market participation by DER. • Ensure connection processes for V2G are transparent to market participants and customers and are stable and smooth • Harmonise connection processes across DNSPs • Ensure that rules and bilateral demand response agreements recognise and encourage value stacking.
3.	REVS	AEMO/energy regulators	The national electricity rules requirements can be a barrier to grid services from distributed resources, including V2G. Rule makers can encourage uptake by: • Ensuring technical requirements are fit for purpose and not onerous for distributed resources. For example, this may include lowering participation thresholds below 1MW. • Ensuring rules do not penalise energy storage (devices that can charge and discharge) • Recognising the resilience benefits of V2G.
4.	REVS	DNSPs/research institutions	Engage proactively with V2G to leverage Australia's success with DER integration by extending existing DER constraint management products to include EVs and V2G. These products can then be exported worldwide.
5.	Future	Standards bodies	Influence international standards as they are reviewed to harmonise with Australian standards and allow for Australian use cases. In particular this includes charging standards (such as those managed by CHARIN).

Customer value proposition

V2G can only become mainstream if people see value in it. This requires that it provide additional services they value, while not impinging too much on mobility.

Table 2 Customer value proposition recommendations

ID	Action type	Who needs to act?	What do they need to do?
6.	Immediate	Trial proponents	A key part of normalising V2G is sharing use cases and building a compelling narrative for V2G. EV/VGI projects can help this process by ensuring development and communications activities include end users. For example, bringing end user feedback into demonstration programs, or developing comms with end users in mind.
7.	REVS	Governments and industry	Consider targeted information campaigns to inform individuals, fleets, and car dealers about V2G and address perceived risks, such as range anxiety and battery health. These programs may work in concert with general DER/grid participation education programs.
8.	REVS	Energy and transport industry	Enhance uptake and broaden appeal of V2G by identifying and then appealing to a more diverse range of customer value drivers (not just financial).
9.	Immediate	Users	Those private and fleet EV owners that are aware of and interested in V2G should engage with industry and governments to make visible their interest, and participate in trials and initiatives.

Open value transfer

Jurisdictions where V2G adoption is strongest tend to have economic mechanisms in place to make the value of V2G apparent. This can be through markets (such as the demand flexibility markets of the UK or California), real-time pricing (such as explored by Sacramento Municipal Utility District), time of use tariffs (such as those tested by Austin Power), or other means. These mechanisms serve as a signal to customers or aggregators for EVs to respond to energy system needs.

Table 3 Open value transfer recommendations

ID	Action type	Who needs to act?	What do they need to do?
10.	Immediate	Energy industry and regulators	Cost reflective pricing is a proven means of incentivising EV charging at times which avoid network congestion. This can be a staged approach: • In the short term expanded use of "time of use" energy and demand tariffs can shift EV charging outside of peaks • As V1G/V2G reduces in cost and aggregation becomes more widespread, dynamic and localised price signals can manage congestion
11.	Immediate	Energy and transport industry	Ensure that grid services customer contracts align with customer's transport values. For example, this may mean avoiding plug in targets that appear punitive.

ID	Action type	Who needs to act?	What do they need to do?

12.	REVS	Energy industry and regulators	Flexibility from V2G can provide services to existing energy markets as well as potential future distribution services markets. The REVS trial will demonstrate V2G providing FCAS services. For these services to expand beyond the trial existing barriers need to be removed or new markets created to transact the value.
			• In the short term remove barriers preventing V2G participating in the market where possible. This includes:
			  ○ Minimum participation volumes
			  ○ Metering requirements
			  ○ Interaction with the distribution system and constraint management
			• In the longer term investigate distribution flexibility markets

Fostering an industry

V2G grid services may be provided by a diverse group of existing and new-entrant organisations. Many of these will not have experience in the energy system and may require additional guidance.

Similarly, for a small market such as V2G, it is important that new technologies and concepts developed elsewhere can be imported and demonstrated easily and quickly.

Table 4 Fostering an industry recommendations

ID	Action type	Who needs to act?	What do they need to do?
13.	REVS	Governments and funding bodies	Trials and demonstrations (such as REVS) are a key part of de-risking new business models. These trials must generate actionable outcomes to relevant issues.
14.	REVS	Governments	Consider short term funding programs to reduce the cost delta between unmanaged, managed, and V2G chargers. Electrification of government fleets and adopting managed and/or V2G charging would be powerful actions.
15.	REVS	Industry, regulators, and governments	V2G and grid services requires collaboration of energy and transport sectors. Similarly, services may be provided by new entrants who have little previous expertise in the energy sector. • Create and foster cross-industry collaboration to build connection between transport and energy industries. • Create mechanisms to educate and build relationships with new entrant grid services organisations
16.	REVS	Energy and transport industries	Import and validate overseas technologies to increase choice and drive down cost in the market.

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

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

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

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

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

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

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

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

1 Introduction

1.1 Purpose

Electric vehicle-to-grid technology enables the energy stored in an electric vehicle's (EV's) battery to be discharged through an EV charger and into the wider electricity system. This concept is of major interest as it can radically increase the utilisation of EV batteries for the financial and non-financial benefit of their owners as well as for the wider electricity system and community.

While vehicle-to-grid (V2G) is conceptually a simple proposition, and has been demonstrated in laboratories for decades, deploying V2G services into electricity systems and markets is more complex. This report reviews all aspects of realising V2G services in the real world.

The purpose of this document is to introduce readers to the concept and implementation of vehicle-to-grid services. We hope it will be informative for readers from a wide range of backgrounds, regardless of location or field of expertise.

This document is also a foundational work for the Realising Electric Vehicle-to-grid Services (REVS) project [1], of which the Battery Storage and Grid Integration Program of The Australian National University is the partner. The REVS project is a trial of V2G using a 51-vehicle fleet of EVs that aims to demonstrate that EVs can deliver frequency support to the live power system via Australia's National Electricity Market (NEM); and to pave the way for the accelerated adoption of V2G services in the NEM.

Our perspective is therefore Australian. To provide some basic context, Australia is a laggard in the adoption of EVs compared to other similar countries, but on the other hand has sophisticated and well-developed infrastructures in place that facilitate the NEM. We have however written the report with both Australian and international audiences in mind and, given that most experience with V2G to date has been gained outside of Australia, many of the included examples are international.

1.2 Scope

V2G is just one part of multiple larger technological transitions, including the electrification of road transport, the decarbonisation of the electricity system through renewable energy generation and energy storage, and the increasing decentralisation of the energy and transport systems with greater customer self-reliance.

This report focuses specifically on V2G services and the many factors that facilitate them. In order to understand these, it's important to consider the broader context of vehicle-grid integration (VGI). We therefore cover recent developments in VGI as necessary throughout the report.

Whilst specific in subject matter, this report is ambitious in its interdisciplinary engagement with the subject. We explicitly cover the social, technical and economic aspects of V2G, presenting them in an integrated fashion that captures their interdependencies. As illustrated in Figure 3, such a holistic engagement with V2G has been sorely missing in trials to date.

Our report is based on an extensive review of the academic literature, reports from industry trials and activities, and regulatory and government policies from around the world. These were complemented by dozens of off-the-record conversations with stakeholders that encouraged frank insights into the state-of-play and the direction of progress. Together, we hope this review provides an approachable yet consolidated overview of the key parts of the V2G puzzle, learnings from practical experiences to date, and outlines of the exciting future of V2G at the nexus of the electricity and transport systems.

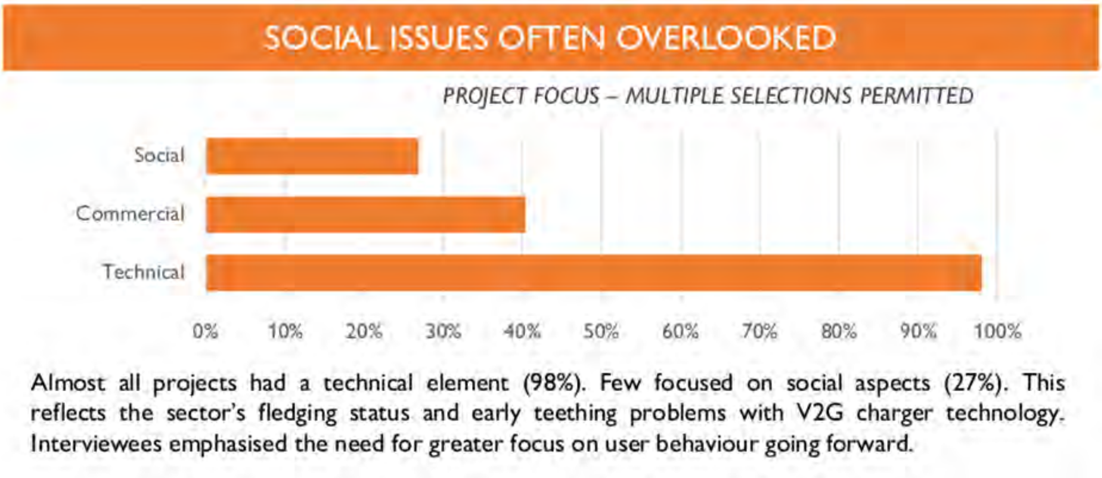

Figure 3: Analysis of 50 V2G trials from around the world shows that social and commercial aspects are usually not considered. [2]

This report provides insights gained from several international initiatives. A list of these is shown in Appendix H.

1.3 Framing

V2G services, and EVs in general, occupy a new position that intersects with the traditional domains of electricity and transport, encompassing the social, technical, and economic aspects of these systems. To make sense of such a broad and varied system we developed a framework that foregrounds (1) the important energy and transport services that these systems provide to people, and the values these services speak to; (2) the economic value that these services can provide; and (3) the specialised techniques involved in managing these services.

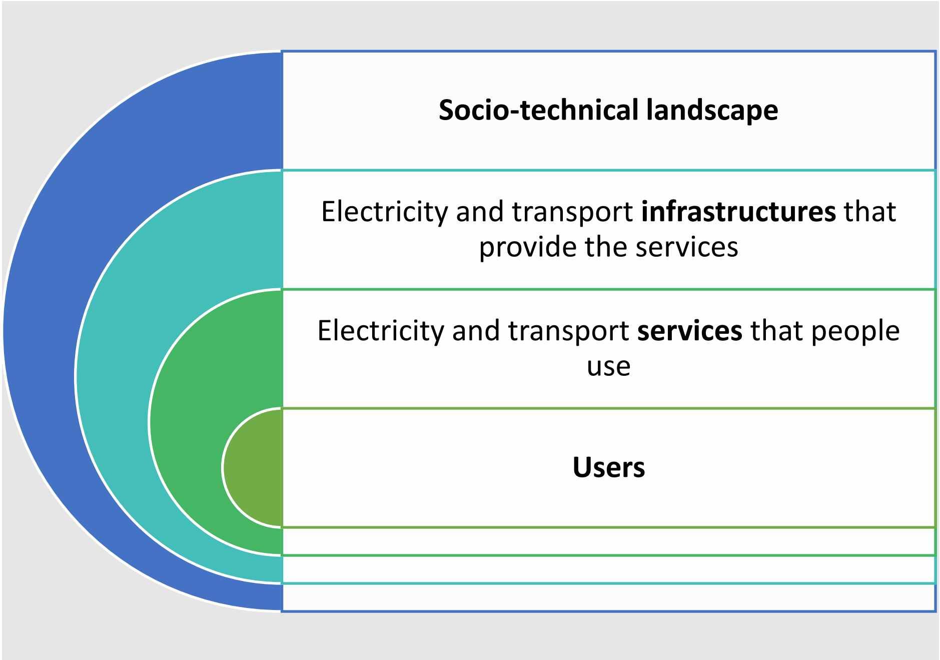

Figure 4: Review framework.

As represented in Figure 4, our framework places the end-users of the transport services that EVs provide and the electricity services that V2G provides at the centre. These services, and the value they offer to the people and organisations using them, are the fundamental reason behind the existence of the infrastructures that provide them. In this report we recognise that the value offered by V2G is not purely economic; important values include independence, convenience, status, affordability, environmental concerns, community-mindedness and trust in institutions and service providers. Likewise, challenges to the up-take of V2G by people, organisations or services provided will take many forms.

The review will also detail how V2G is or can be enabled by infrastructures, taking a broad definition to include not only physical network infrastructures, but also the markets, rules and codes that underpin them; the business models that facilitate participation in the market by DER installations; and the hardware, software and standards that are needed at the charging point. By interacting with networks and markets, V2G has the potential to improve the way they produce and distribute electricity to end-users, as well as deal out new challenges to network planning and practical implementation.

V2G is playing out within a much larger socio-technical landscape characterised by uncertainty and change. Our review therefore considers the landscape pressures wrought by broader issues including the energy transition and climate change.

1.4 Structure

The report is structured to achieve two goals: (1) allowing readers to identify and focus on their priority interests; and (2) presenting an integrated view of V2G at the energy-transport nexus. We believe that the true value of the report stems from this latter, holistic coverage and encourage readers to read the report sequentially and in its entirety.

The first sections of the report detail the current state of V2G. Chapter 2 reviews the relevant background context on the energy and transport systems, and Chapters 3 and 4 present the perceived benefits and challenges of V2G. The latter part of the report is focused on the future of V2G. Chapters 5 describes the implementation landscape that V2G proponents will need to operate within, including the technology, markets and policy, business models and future trade winds that could support or hinder V2G endeavours. Chapter 6 presents a collection of policy and regulatory proposals to accelerate adoption of V2G as well as deal with potential speedbumps.

Lastly, we note that all figures reproduced from the literature have their original sources referenced in their captions. All figures without references have been prepared by the authors for this report.

2 Background

Access to electricity and far-ranging mobility are defining features of modern life, especially in wealthy nations. The importance of these services is reflected in societies' long-standing dedication of considerable human and natural resources to their provision: In Australia, the transport and electricity sectors together employ hundreds of thousands of workers [3] and consume such volumes of fossil fuels that they are responsible for over half of Australia's carbon emissions [4].

These previously quite distinct sectors – of transport and electricity – are becoming tightly coupled as electric vehicles become increasingly superior to internal combustion engine vehicles across the metrics of driving experience, total cost of ownership (TCO), convenience, environmental impacts, and new services such as autonomous driving and V2G. V2G services epitomise this "sector coupling" as electricity, responsibilities, and remunerations flow in both directions between vehicles and the grid.

The significance of this coupling is tremendous. If all of Australia's 19 million vehicles [5] were electrified, they would increase Australia's electricity consumption by one third [6]. The scale of this challenge is matched by the scale of the opportunity, as these vehicles would have roughly the same energy storage capacity as five Snowy 2.0 pumped hydropower schemes [6] - the largest energy storage infrastructure ever conceived of in Australia. Such dispatchable energy storage is increasingly vital for the secure operation of the energy system as variable renewables generate an ever-increasing proportion of the energy mix.

Beyond the scale of these techno-economic systems, sector coupling is important because it will profoundly reshape people's conceptions of these essential services and how businesses provide them.

In this section, we introduce the V2G concept and the different stakeholders from the transport and energy sectors involved in deploying and operating V2G services. From there we detail the infrastructures required to enable V2G at scale, including electricity networks and markets, communication rules and standards, physical technology and business models. Finally, we position V2G in the over-arching socio-technical context.

2.1 The V2G concept

Electric vehicle grid integration (VGI) services are, at their core, about managing EV charging and discharging to meet the needs of the electricity grid, within the constraints of EV's mobility use. This can help avoid a bad outcome, such as overloading the distribution network, and can create good outcomes, such as taking advantage of low market prices. V2G is differentiated from other VGIs in that only V2G vehicles can discharge power from their battery into the grid when they are plugged in to a V2G enabled charger [7] [8].

A central aspect of the appeal of V2G is that it utilises existing batteries, sitting idle whenever an EV is not being driven, to provide valuable energy services to the grid. This has the potential to be both cost-effective within the energy market, which should result in downward pressure on energy prices, as well as providing income for the owners of vehicles and chargers. These are just some of the potential benefits of V2G that will be covered in this report.

The concept of V2G goes back to the 1990s [9], but it is yet to be fully commercialised. This step requires a wide range of infrastructures to be in place and available, including (1) an appropriately equipped EV and charger; (2) a communications platform to control charging and discharging; and (3) metering and auditability of services rendered [7].

Before narrowing in on V2G, it is essential to understand V2G in the broader context of VGI methods. Commonly VGI methods are grouped into three categories as shown in Figure 5. Each step up in sophistication is considered to deliver greater value to vehicle owners and the grid by either unlocking new services or delivering existing services in an improved manner.

Behavioural control (V0G)

The simplest means of implementing charger control is through customer behaviour. This involves indicating to customers when are good times to charge their vehicle and relying on the customer to charge at those times. Most customers have access to this type of control today through time-of-use price signals, however EV-specific products also exist. Usually signals are static (the same every day) to manage complexity however some more dynamic models have been demonstrated.

Managed charging (V1G)

The next logical step is to automate the charger's response to control. This involves adding a communications link to the charger and implementing a control and orchestration system. Customers may interact with the charge process via a web interface or similar. In literature this is be referred to as "V1G", or "G2V".

Bidirectional charging (V2G)

The final level in functionality is to enable vehicles to discharge power out of the battery. This enables more services more often. When the discharged power flows into the electricity grid, this functionality is referred to as vehicle-to-grid (V2G). When the power is discharged into buildings the service may also be referred to as "Vehicle-to-building" (V2B), or if the building is a home "Vehicle-to-home" (V2H). In this report we use the term V2G when the service being delivered is for the benefit of the grid, even if the vehicle is connected within a building, and use the term V2B to cover services delivered for the primary benefit of the building occupant (including when the building is a home).

Another term used to describe the ability of EVs to discharge power is V2X, where the "X" highlights that any number of electrical appliances or systems can be the recipient of the vehicle's energy. In this report we use V2X to refer to applications not covered by V2G or V2B.

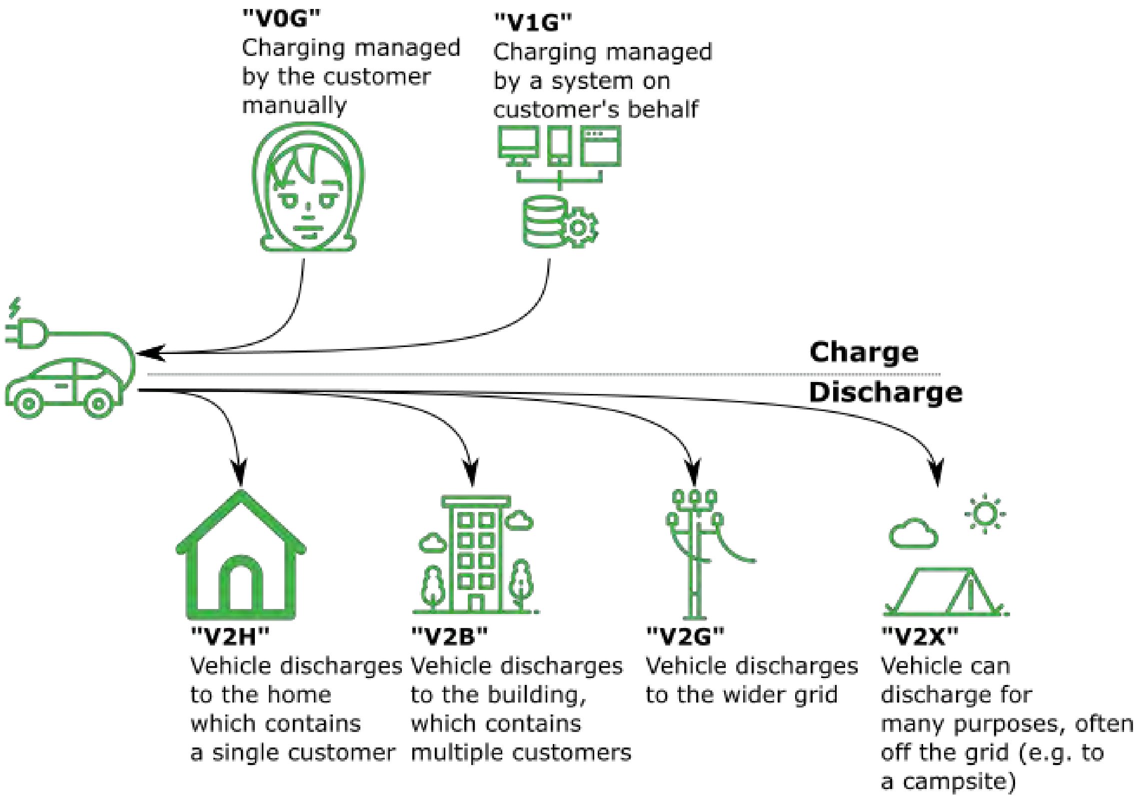

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Figure 5: Bidirectional charging domains

2.2 Landscape

The electrification of vehicles represents a fundamental shift in the way people power their mobility, from a system based on liquid fuels and internal combustion engines towards a fully electric system with a corresponding reliance on electricity infrastructure for charging. This intersection of the transport and electricity systems is referred to as “sector coupling”. V2G sits at the heart of this nexus (see Figure 6) and makes this a reciprocal relationship as the electricity system may become reliant on the energy stored in EVs.

While V2G and sector coupling represent profound changes for both sectors, it is a particularly radical proposition for the transport sector. The electricity sector can conceive of EVs as “batteries on wheels” as a type of Distributed Energy Resource (DER). DERs are assets that are relatively small; are installed in the distribution network, typically on customers’ properties; are often owned by customers and facilitate customers to participate in energy markets [10]; and, generally, have digital interfaces that facilitate high levels of remote control. The electricity sector is increasingly familiar with DERs such as rooftop solar and stationary batteries, particularly in Australia [11]. The transport sector on the other hand has no experience with generating revenue from assets from anything other than mobility services.

In the remainder of this section we familiarise readers with the many actors in the existing electricity and transport sectors, which lays the foundations for our later discussions of the roles and future prospects of service providers in the coupled transport-electricity system.

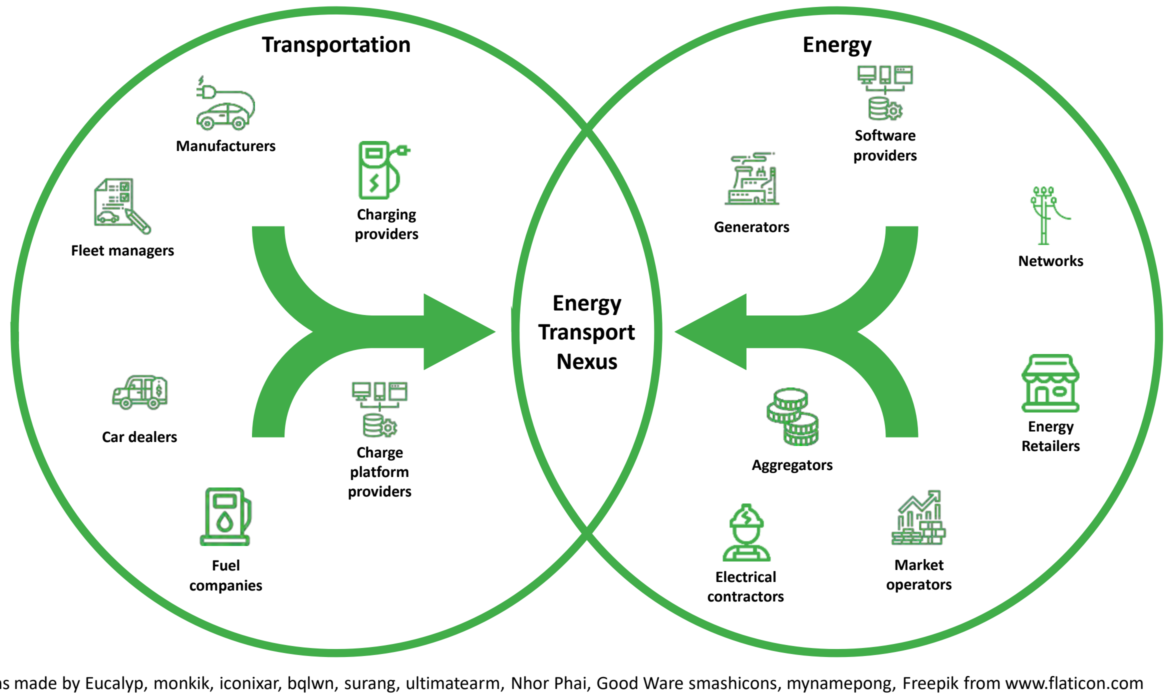

Figure 6: Transportation energy nexus

2.2.1 The energy landscape

The key actors in the energy sector landscape are shown in Figure 7. Roles and titles are based on the Australian context and may be defined differently in other jurisdictions.

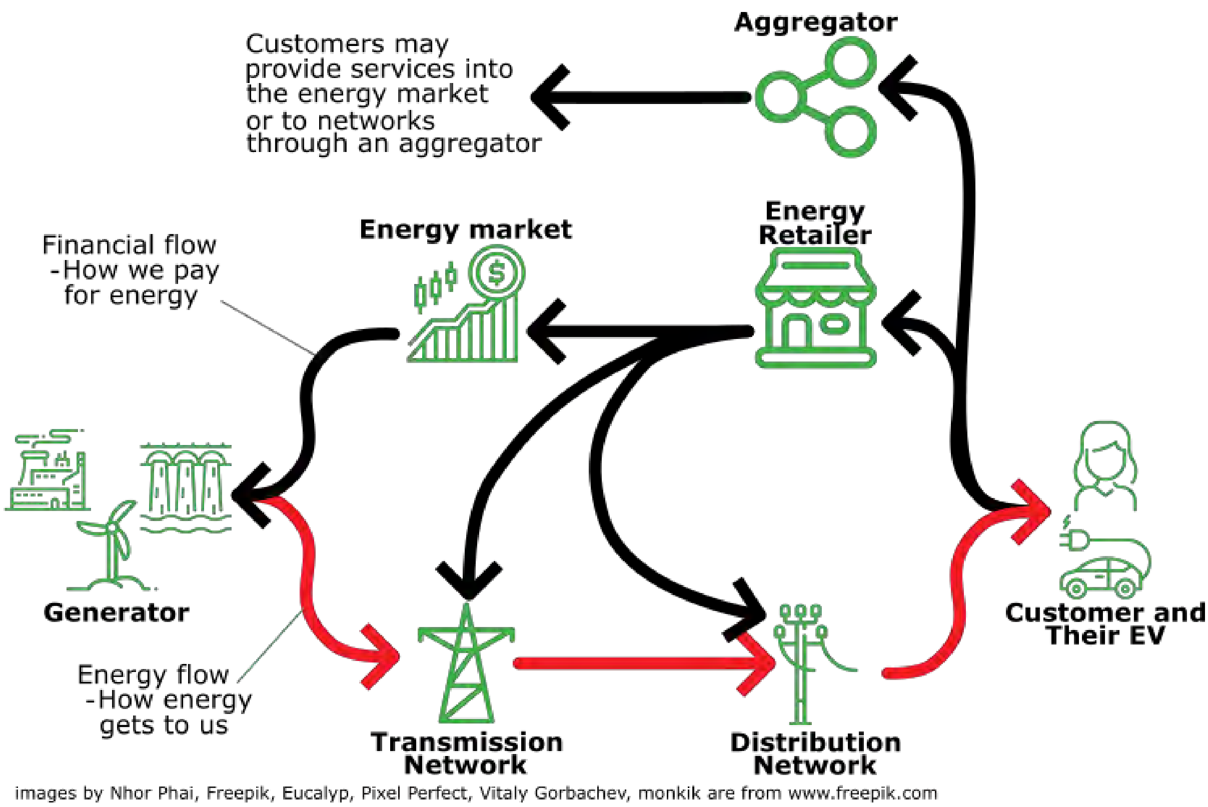

Figure 7: Energy market

Technically, energy flows from generators, through the transmission and distribution network and to customers.

Financially, generators are dispatched via a market. Retailers aggregate energy market charges, transmission, and distribution charges and present this to customers as a single unified bill. Additionally, customers may appoint an aggregator to provide services into the market or to networks on their behalf. Other roles may also provide other services such as metering, equipment installation and maintenance.

Energy sector actors are the customers of grid services and are also the main provider of these services currently, which positions them well to evolve into providing EV-related grid services. Energy sector actors are described in Table 5.

Table 5 Energy market participants

Generators	
What do they do?	**Role in EV grid services**
Generators currently operate large-scale centralised generators. These are traditionally the source of many of the grid services that EVs may provide in the future. They are not a customer facing organisation however in Australia most generators have a relationship with a retailer. Examples: Hydro Tasmania	The impact of V2G on a generator will depend on the service footprint of the generator. Generators that currently offer grid services such as frequency control or peaking generators may lose as EVs begin to provide those services. While other generators (particularly renewable generators like wind) may benefit from firming services from EVs.
Networks	
What do they do?	**Role in EV grid services**
Networks own and operate the 'poles and wires' that transport energy from generators to customers. They are not active market participants but are responsible for managing the capacity of their network. They are not a customer facing organisation. Examples: Evo Energy, Ausnet services	Networks have a large role in EV grid services. Together with the market they are one of the largest customers of EV services. They need to manage network capacity issues arising from EVs providing other services. Usually networks ultimately approve connections of embedded generators (such as V2G chargers) Example: Shift (UKPN)
Energy Retailers	
What do they do?	**Role in EV grid services**
Energy retailers package market price and network charges and offer it to the customer as a consumption tariff. They have a day-to-day relationship with customers. Examples: ActewAGL, Powershop	Energy retailers have an interest in EV grid services both as a customer and as a service provider. Because they are market exposed demand flexibility can reduce their input costs. Example: Project Sicurus (OVO)
Market Operators	
What do they do?	**Role in EV grid services**
Market operators are responsible for the day-to-day operation of the market. They often have the ultimate responsibility for system security. They are not active participants in the market and will usually only procure services as a last resort (e.g. RERT).	Market operators have an enabling role. They can assist uptake by ensuring that standards and rules for market participation are designed to enable grid services from EVs. Example: VPP demonstrations (AEMO)

Examples: AEMO, CAISO	
Aggregators	
What do they do?	**Role in EV grid services**
Aggregators bundle distributed energy resources on behalf of customers in order to engage as a single entity in power or service markets. They are a relatively new market participant, made possible by increased digitalisation and smart metering. Examples: Reposit Power, Enel-X	Aggregators already provide similar services, possibly with other types of assets (e.g. batteries for Reposit Power). EVs may be another service to integrate into their products. Example: eMotorWerks California VPP (Enel-X)
Electrical Contractors	
What do they do?	**Role in EV grid services**
Electrical contractors in most cases install EV chargers. They have a major role in helping customers select products that can provide the services that they require. Examples: I Want Energy (Tasmania)	Electrical contractors assist customers to select, install, and maintain charger hardware. This means their role is key in ensuring physical demand response/V2G capability exists. They may be the party to introduce customers to the concept of grid participation.
Software/platform providers	
What do they do?	**Role in EV grid services**
Software platforms provide key energy services. For example, metering and Supervisory Control And Data Acquisition (SCADA) services. Providers of these platforms often handle large volumes of data and already have links to utilities. Examples: Brave metering services	These organisations may not have a direct role in EV grid services, however as they already provide big data services, EV services may be an opportunity for market expansion.

2.2.2 The transport landscape

The impacts of VGI services on the transport sector are intricately linked to electrification in general. Private and commercial transport stakeholders have not historically needed to interact with electricity to any great degree and have definitely not been the producer or buyer of grid services. To begin to understand the journey facing transport system we outline the roles of existing actors in Table 6, including their potential future roles in VGI.

Table 6: Key transport sector stakeholders.

Vehicle manufacturers	
What do they do?	**Role in EV grid services**
Vehicle manufacturers manufacture and support electric vehicles. They are a key enabler of grid services through their technology choice, marketing, and warranty conditions. Examples: Nissan, Tesla, Hyundai, BMW	Provide physical capability in vehicles. Support V2G and grid services at a hardware level and in warranties. Visibly support grid services to the wider public and to customers. Example: ChargeForward (BMW)
Charging Providers	
What do they do?	**Role in EV grid services**
Charging providers manufacture, install, and support EV charging hardware. Examples: Tritium, JET Charge, Nuvve	Provide hardware that is capable of delivering services. Provide software platforms to enable delivery of services. Example: e-flex (Nuvve)

Fleet Managers	
What do they do?	**Role in EV grid services**
Fleet managers manage groups of vehicles. There are many different types of fleet managers. For example: • Fleet management companies (e.g. SG Fleet) • Organisations with large fleets (e.g. Australia Post) • Car share companies (e.g Uber) • Public transport and taxi companies (e.g. Transport Canberra) These organisations will often be responsible for introducing (particularly commercial) customers to grid services.	Integrate grid services into existing products. Help customers and businesses along the journey to provide grid services. Example: Zebra (CTE)
Car dealers and service agents	
What do they do?	**Role in EV grid services**
Car dealers and service agents are the "front line" in customers purchasing and maintaining vehicles. They are key intermediaries in a customer's grid services journey. They may be the party that introduces customers to the concept of grid services.	Inform customers that grid services are possible Help customers understand the impacts of grid services on their vehicles. Act as a conduit into grid services products. Service agents will see a significant change in skill requirements with electrification of transport.
Fuel Companies	
What do they do?	**Role in EV grid services**
Fuel companies currently focus on the liquid fuel supply chain. They manage large amounts of infrastructure within this chain, terminating in fuel stations all over the world. Electric vehicles will cause a significant decline in fuel requirements. Examples: Shell, BP	Fuel companies' role in grid services is currently unclear. EV charging at current petrol station sites may require significant storage to manage demand and domestic charging may be a means of capturing value that would otherwise be lost. Example: Pitpoint clean fuels (Total)
Charge platform providers	
What do they do?	**Role in EV grid services**
Charger platform providers manage fleets of chargers. They manage authentication, billing, and access. They may also manage energy tariffs. These platforms can often be easily repurposed for grid interaction. Examples: Chargepoint, Chargefox, Evie Networks	Grid support uses much the same communications infrastructure as charger fleet management. Grid services at some level are likely a closely adjacent service for most platform providers Example: JuicePlan (Enel-X)

2.3 Enabling infrastructures

V2G is dependent on a range of enabling technologies and infrastructures. These include vehicles, chargers, controls and communications protocols, as well as market structures and wider policy frameworks. As additions or modifications to the status quo, there is some work to be done to put these infrastructures in place, which may face resistance on the grounds of cost and complexity, as well as vested interests.

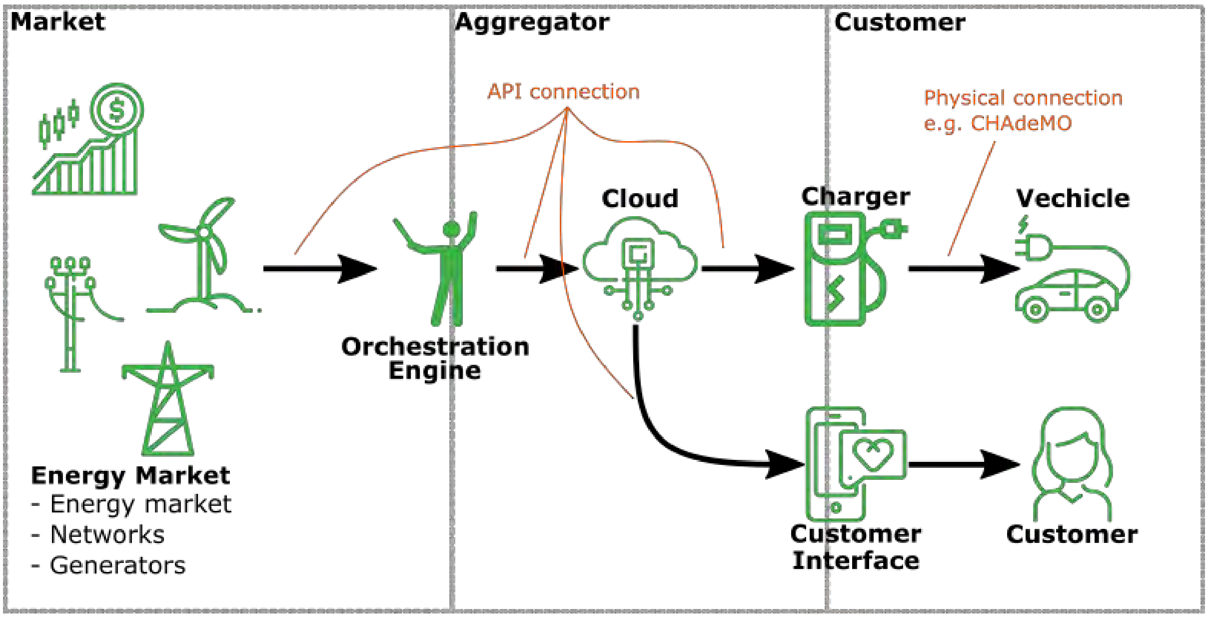

Figure 8: V2G implementation architecture.

A summary of the technical and infrastructure stack used to deliver V2G services is described in Figure 8, highlighting:

- The **Energy Market** are the parties who would like demand or generation profiles altered to meet needs (e.g. manage peak demand). They provide signals indicating timing and level of service required
- The **orchestration engine** optimises the multiple needs of the energy market and customer preference to create EV charge requests
- The **cloud** is the bridge between the orchestration engine and the customer interface and their charger/car.
- The **charger** and **vehicle** manages power flow into or out of the car (in some cases the charger may be located within the vehicle).
- The **customer** provides consent to requests issued by the aggregator and sets the relative value of the prospective value streams

2.4 Socio-technical context

Widespread adoption of new technologies such as V2G and EVs will require the technologies to be understood, accepted, and seen to be valuable to vehicle owners, service providers across the electricity-transport system, and society more broadly. There are a number of frameworks that help make sense of new technology adoption and wider socio-technical change [12]. Three have been shown to be particularly helpful in considering EVs and V2G: 1) diffusion of innovation, 2) social construction of technology, and 3) the multilevel perspective [7].

These are described in more detail in Appendix F but in short, diffusion of innovation theory describes the social processes of adopting and then communicating about new technologies through interpersonal networks and the modelling of their use [13], [7], [14], [15]. Social construction of technology theory argues that technologies are fluid, not fixed, and are 'co-constructed' by users through a process called interpretive flexibility, which ascribes new meanings to technologies [12], [7]. An example can be seen in how rural Americans adapted the early Model T Ford to provide a source of stationary power and a makeshift tractor on their farms, smoothing the adoption of the car [16]. The multilevel perspective focuses on systemic changes and contestations as innovations become part of the established socio-technical system—or are resisted by incumbents [17], [18], [7], [12].

Taking the three approaches together helps address their individual gaps. It also allows us to take a holistic view of the wider electrical and transport regimes that V2G and EVs operate within, while retaining sufficient granularity to examine the many roles of users in actively adopting, adapting and advocating for the technology in response to the changing socio-technical landscape. This helps us ask questions like 'why' and 'how' people and organisations are making decisions about V2G and EV technology, to consider the potential for opposition from negatively affected incumbents, and to ensure that V2G schemes reflect attributes like fairness, transparency and trust that we know are critical to promote social acceptance of new technologies [19].

3 Benefits

Driven by strong environmental and community values, increased availability and affordability, and a crisis of trust in the energy sector, Australia continues to see rapid uptake of distributed energy resources such as solar power and, increasingly, battery systems, as well as nascent interest in demand response capability in devices such as air-conditioning. This decentralisation is occurring in both the residential and commercial sectors, albeit at different scales and implementations. EV uptake, too, is expected to increase markedly in the coming decade, with some projecting EVs will make up 50 per cent of Australian vehicle sales by 2030, and 100 per cent by 2040 [20]. While the magnitude and patterns of these devices' power use/generation creates challenges for the electricity network (as will be discussed in section 4.2), their digital nature creates significant opportunities for them to contribute to the management of the production, delivery, and use of electricity, and V2G provides the capability to take those opportunities.

The key feature of the V2G concept is that it takes an existing asset – the EV battery – and gives it the capabilities of a modern grid-connected battery. In this context, V2G technology offers a range of compelling private, technical, economic and social benefits. V2G is expected to provide valuable support to the grid including through frequency control and ancillary services (FCAS), energy at times of peak demand, and the integration of higher levels of renewable electricity. This has the potential to lower the cost of energy and transport for households and businesses; create greater energy self-sufficiency and resilience at the user, local and national levels; and give rise to significant climate and health co-benefits. Collectively, these benefits are likely to resonate with different values of individuals and organisations, and this may represent both a business opportunity in the near term, and a pathway to help rebuild and reconfigure trust in the energy sector in the longer term.

It is important to note that some of V2G's benefits exist in the very near term, while others will take longer to realise. Still others are not currently known and may only become apparent over time, reflecting V2G's relative novelty. Additionally, V2G operates in a complicated socio-technical system, with a wide range of parties involved ranging from vehicle owners, EV and charger supply chains, through to aggregators, electricity companies and regulators, as well as potentially competing technologies, such as large stand-alone batteries. V2G can accordingly be expected to benefit and impact groups differently. Finally, some benefits are likely to accrue to individuals, with others accruing to society as a whole [7] [21].

This chapter will set out the key benefits of V2G, starting in Section 3.1 with those accruing to people and organisations as the primary beneficiaries of the services that our transport and electricity systems provide. Section 3.2 will then set out the potential benefits to the management, operation and efficiency of electricity production and delivery systems. Finally, Section 3.3 will take a broader view, discussing the societal co-benefits that V2G can deliver.

The benefits presented in this chapter are summarised in Table 7, where potential recipients of benefits include Transmission Network Service Providers (TNSPs), Distribution Network Service Providers (DNSPs), and Original Equipment Manufacturers (OEMs), amongst others.

Table 7 V2G EV benefits

Benefit	Who it applies to	Reference
Affordability: Better management of energy flows and shift to electrification can reduce overall electricity and transport costs	EV owners	3.1.1
Resilience: V2G could provide the means to deploy back-up power during outages and emergencies	EV owners DNSPs Emergency and community orgs	3.1.1
Appeal to values: V2G and EVs can signify status and sustainability	EV owners	3.1.1
Differentiation: Service providers can offer a new product that connects them with user groups and align values, and improve business sustainability into the future	Aggregators Retailers Fleet managers OEMs	3.1.2
Balancing intra-day supply and demand: V2G can improve electricity system flexibility to meet demand, including better utilisation of renewable energy	TNSPs/DNSPs Energy market	3.2.1
Valuing services through markets: V2G can enable end users and service providers to participate in the energy market	EV owners Aggregators	3.2.1
Managing frequency: V2G can provide frequency control services to help manage supply-demand mismatch and incorporate more asynchronous generation	TNSPs/DNSPs	3.2.1
Congestion management: Smart charging and V2G can avoid local network congestion caused by peaks and defer network investment	TNSPs/DNSPs	3.2.2
Power quality: Smart charging and V2G can improve power quality by controlling voltage and power factor	TNSPs/DNSPs	3.2.2
Network security: V2G can improve the network's ability to quickly respond to sudden disturbances	TNSPs/DNSPs	3.2.2
Data and demand forecasting: Smart charging and V2G can provide networks with anonymised charging data to improve network planning and operation	TNSPs/DNSPs	3.2.2
System resilience: V2G can improve the system's ability to anticipate, absorb, adapt to and recover from faults by improving frequency control and providing backup power	EV owners TNSPs/DNSPs	3.2.2
Equity: V2G and other low-cost forms of dispatchable storage should put downward pressure on electricity prices. Lower electricity prices disproportionately benefit people on lower incomes.	General public	3.3.1
Health and climate: By assisting the transition towards renewable energy and transport electrification, V2G supports cleaner air and lower greenhouse gas emissions	General public	3.3.2
Trust: V2G may contribute to improved trust in the electricity market by increasing autonomy and perceived benefits to end users	EV owners General public	3.3.3

3.1 New value streams

This section will begin by setting out benefits to users of V2G, being owners and users of V2G-enabled EVs in residential and organisational settings, including discussion of how V2G may resonate with their values and aspirations. The second part of this section discusses benefits to service providers including aggregators and other organisations that play a role in making V2G available to users.

3.1.1 To users

Affordability

V2G has the potential to reduce utility costs to users in three key ways: by reducing retail energy costs; generating income; and placing downward pressure on wholesale prices. These benefits are possible due to enhanced ability to manage electricity and a new ability to trade energy, encompassing greater volumes of energy due to the transition away from liquid transport fuels. This section will discuss the first two aspects of affordability which accrue to end users. The third aspect however, relating to wholesale prices, accrues to all energy users. The mechanics of this in relation to the electricity system will be explained in section 3.2 and the resulting societal benefits set out in section 3.3.

The following sections describe how users can maintain the existing level of service they derive from electricity and transport systems at a lower cost, through the use of V2G. This is achieved in multiple, interlinked ways involving where their energy comes from – be it the grid, on-site renewables, or refuelling stations – and how they use it.

Vehicles, be they electric or otherwise, will often be the most energy consuming device at residential premises, and a significant cost to organisations with fleets. A key difference between EVs and fossil fuel vehicles is that the energy storage capacity of EVs can be used to pursue multiple financial and non-financial objectives [22]; one being improving affordability through the management of on-site energy in the V2H or V2B domains (refer Figure 5). These possibilities exist because the time at which EV charging occurs is very flexible. EV batteries can be best optimised by integrating the V2B system with a Building Management System (BMS) or Home Energy Management System (HEMS) which can manage EV charging and discharging in concert with whole of building loads and on-site generation [23]. Such integration has been demonstrated by Japanese automotive component manufacturer DENSO and Toyota EV [24].

Over 80% of EV charging currently occurs at home [25]. Internationally, EV owners have high rates of rooftop solar adoption compared to the general population, particularly in countries where solar is popular – for example, it is estimated that 60% of EV owners in the Netherlands have rooftop solar [26]. This group can shift the charging times of their EVs to coincide with sunny periods to take advantage of free or low-cost energy generated on site. With V2B/V2H technology, this stored energy can also power the property at night and other times of low or zero solar generation. Integrating solar and V2G capable EVs in this way can reduce peoples' reliance on electricity imports [7], increases their solar self-consumption [27] and subsequently maximises the return on their solar and EV investments [28].

The exact economics of solar self-consumption will depend on the difference between the consumption rates and solar export rates. In Australia, solar feed in rates vary between 6 and 29c/kWh [29]. In the US rates vary between $0 and $0.79/kWh (AUD) [30]. In the UK solar feed-in tariffs vary by retailer, with one retailer offering 5.5p ($0.10 AUD) [31]. Customers with a higher solar export rate will have less incentive to charge using solar energy. In cases where the export rate exceeds the lowest possible consumption rate, customers may be incentivised to move consumption outside of typical solar generation periods [28].

The simplest and lowest cost means of charging with solar energy is by timing charge to occur during the day when it is usually sunny [32]. Excess usage not covered by solar generation in this case will be sourced from the grid at the grid energy rates. V1G Smart chargers can manage charging to use solar generation better. There are products available in the Australian market with this capability [33].

Aside from low cost on-site solar energy, EV charging costs can be minimised by coinciding charging with times of lower-cost grid energy. This doesn’t require V2G, however V2G can unlock extra value. Electricity tariffs are priced in a variety of ways worldwide, increasingly in a way that is more reflective of their impact on future network costs, via demand (time of use or flat), time-of-use energy, or fixed charges [34]. The aim of these prices is to ensure that the system is operated efficiently in the short term, and in the long term it promotes the path of least-cost development [35]. An expansive description of different tariff structures offered worldwide that can be used to reduce the cost to charge an EV is included in Appendix G.

Non-residential premises subject to maximum demand or kVA charges may also have strong incentives to use V1G and V2G charging in concert with a BMS. V1G can avoid EV charging contributing to maximum demand, and V2G-enabled fleets could reduce maximum demand caused by other peaking loads such as air conditioning. An example of this was in California where V2G capable electric school buses were used to offset the additional demand charges of a compressed natural gas filling station. This trial showed the school buses reduced the net energy charge by USD $5,000 ($6,843 AUD)/bus/year [36].

Because V2G and energy management systems can lower the cost of running an EV, they also improve the total cost of ownership when compared with fossil fuel vehicles. An important part of this is the shift from liquid fuels which, once purchased at a retail outlet, are no longer tradeable, to electricity, which with V2B can be repurposed on premises and with V2G can be traded in the electricity market. In this sense, V2G makes the energy used to obtain transport services more “liquid”.

This additional flexibility, as well as the simple growth opportunities, means that electricity retailers and aggregators are likely to have an interest in the electrification of transport and may offer particularly attractive rates for EV charging to encourage uptake. V2G offers from retailers or aggregators can be packaged up in various ways that might include fixed monthly subscription fees for charging (for example [37]).

The final benefit directly accruing to users is income generated from providing V2G services. Participants will expect to be remunerated in some form for the use of their EV battery storage, and so V2G may also open new sources of income for households and businesses with V2G-compatible EVs, as well as V2G aggregation businesses [7]. Depending on the design of the customer offer (e.g. an upfront discount on the EV or charger, ‘get paid as you go’, a reduction in the cost of another service e.g. electricity, or an annual ‘bonus’) this could indirectly or directly reduce the cost of V2G-compatible EVs, and so incentivise EV uptake more broadly [7], [38]. Examples of offers are included in Appendix B.3.

Resilience

The same bi-directional charging technology that supports V2G also allows individual V2G owners to use their batteries to power their homes (vehicle-to-home, or V2H) and similar applications at scale such as vehicle-to-building (for example by government or commercial V2G fleet owners); vehicle to load (for remote industrial users); and vehicle to community.

Vehicle to ‘X’ is another possibility, where X stands for the range of other imaginable applications such as at campsites, work sites or other mobile applications (Figure 5). These use cases support real and perceived energy resilience (or self-sufficiency) for end users and consequent feelings of empowerment. Individuals and fleet owners could use V2H and vehicle-to-building to reduce their reliance on electricity imports [7] and buffer against increasing electricity prices.

V2G may also have resilience benefits at a national level by providing V2G owners with new capabilities to help others. V2G and related applications may increase national energy self-sufficiency and resilience [21], including to shocks and natural disasters – for example, the Black Saturday bushfires in Victoria led to a major program to install back-up generators at vulnerable community facilities [39], and indeed V2G was developed in Japan partly as a response to the Fukushima Daiichi nuclear disaster [40]. Uniquely, EVs can be used to transport energy from functioning chargers to locations in need of electricity, as well as to provide power in remote locations such as when camping [41]. When needed, V2G owners could use their batteries as a source of back-up power to their house, and vehicle to load could support critical premises or construction projects that have lost grid connection [7]. Research suggests people can place a high value on backup power, even at the expense of trading opportunities [42]. A recent Australian report recommended that networks seek a better understanding of the value placed on resilience by the community, and potentially that energy system rules be changed to define and incentivise resilience [43].

Because they have large batteries, EVs are well suited to providing backup power [44]. This has been demonstrated in multiple trials [45]. A 64 kWh LEAF has been shown to be able to supply an average Japanese home’s energy needs for four days [46]. A similar quantum of backup would be possible for a typical all-electric home in the Australian Capital Territory which uses around 20 kWh per day [47]. Another study has demonstrated that a 32 kWh EV can provide 300 hours of continuous backup household supply when combined with solar generation [48]. EVs can also be incorporated into larger buildings and microgrids, and this has been demonstrated in practice. Since the 2011 Tōhoku earthquake and tsunami caused power outages to more than 8 million households in Japan, Nissan has provided LEAFs with portable V2G chargers to supply power to community buildings such as hospitals, community halls, and convenience stores [46].

Applications such as these can allow residents to buy essential goods when most other businesses are still shut down [49] or ensure reliable supply to customers with electrical life support equipment [41]. For these customers, power supply is extremely important, and loss of supply can even result in fatalities [50]. Flexible backup power is also valuable to DNSPs as it can help reduce the impacts of planned outages, which are necessary periodically to maintain or replace electricity supply equipment.

However, providing backup power as an isolated (“islanded”) power source requires the EV or charger to act as voltage source, generating its own voltage waveform, rather than following the voltage waveform measured in the grid. Islanded operation is therefore more challenging than on-grid operation.

Appeal to values

There is a large and growing body of research on the patterns of adoption of technologies that address sustainability problems, including people’s willingness to pay for them. Some studies specifically address V2G, but relevant insights can also be gained from those dealing with low energy technologies more broadly.

One study concluded that people's evaluations of energy alternatives are driven by whether they value nature or wealth more strongly, with wealth-oriented people more driven by the individual consequences of their choices and nature-oriented people more concerned with environmental consequences [51]. In appealing to wealth-related values, there is good evidence on the importance of status-seeking behaviour in driving consumption decisions, including about cars, a concept known as conspicuous consumption [52], [53]. Tesla has been widely credited with making EVs 'sexy', and rehabilitating—at least among men—their perception as boring or ugly [15].

Likewise, EVs charged using renewable energy could appeal to people who are more nature-oriented. A Nordic survey found that renewable and hydroelectric fuel sources made EVs more attractive to consumers – as did range and V2G capability [21].

This may have relevance to V2G: for example, if made sufficiently visible [7], the technology could potentially convey similar status of environmental awareness or technology savviness to individuals as EVs already do. However, other studies have found that political orientation is a more important factor in willingness to pay than consumer values [54]. It should also be noted that messaging to appeal to certain value sets may have a negative impact on groups with different values.

Willingness to pay by the corporate sector may be simpler to identify. The EV100 initiative [55] encourages companies to commit to transitioning fleets to EVs, as well as supporting staff and service providers to do the same. This program has started influencing Australian companies; in the first example, participation was driven by the company's internal climate change targets and strategies [56].

Case study: Conspicuous green consumption (Nordics)

In a 2019 study, Noel, Sovacool et al. report on research in five Nordic countries—Iceland, Sweden, Denmark, Finland, Norway—into the importance of conspicuous consumption for EV diffusion. The study integrates conspicuous consumption theory and diffusion of innovation theory to argue a new concept of 'conspicuous diffusion' may help efforts to understand and promote EV purchasing decisions. Indeed, one of the experts interviewed as part of the research argued that selfish motives were just as important as pro-environmental ones for EV buyers. Telsa's efforts to 'normalise' EVs among consumers and other OEMs are significant in this regard, although their desirability as status symbols may decline over time as they become more common. Importantly, the study considers gender implications, noting that Tesla seems to be targeting male buyers (e.g. their sexualised model names, S3XY) and that EV ownership in the Nordic countries is currently 'overwhelmingly male' [15].

Implications: governments and industry should consider measures that help EVs 'stick out' in order to bolster the symbolic status of EVs, for example through stickers on cars and public V2G chargers, dedicated lanes, etc. Governments should likewise avoid measures that diminish the symbolic aspects of EVs or make them less conspicuous. Somewhat counterintuitively, it might support faster EV diffusion in the short term for EVs to have a price premium reflecting their desirability. Further research on the gendered aspects of EV purchasing decisions would be valuable.

3.1.2 To service providers

V2G represents an economic opportunity across the supply chain. It involves the recognition and commoditisation of new value from existing assets (EV batteries), creating a new space for aggregators between the market, network, and customer, and provides a point of differentiation for manufacturers, suppliers and service providers. This section will outline potential competitive advantages that may emerge from V2G. New business models that may emerge are detailed in Section 5.3.

A feature of innovation is the capture of customers by offering a differentiated product, and particularly in the case of product-services like cars, the formation of lead user or interest groups seeing themselves as "involved" [57]. Most EVs and chargers do not currently have V2G capability, meaning that V2G is potentially an effective differentiator around which user groups can form.

Likewise, V2G's potential to convey green 'status' (refer section above) could represent a positioning opportunity for V2G service providers—from manufacturers, fleet managers, financial institutions, aggregators and even energy networks or retailers with V2G offering—who may be able to leverage V2G's perceived meanings to attract and retain customers.

However, other V2G benefits like affordability and self-sufficiency may be of more salience to many consumers, and an exclusive focus on 'green' status may provoke a reaction from some [58]. As noted in Appendix B.3, existing V2G offers emphasise savings, resilience and convenience to their prospective customers. Perhaps equally importantly, in a time where increasing attention is being paid by investors and regulators to climate risk (see for e.g. [59], [60]) V2G may also help energy and transport companies to increase the longer term sustainability of their business models.

3.2 Electricity system

This section details the features of V2G which have the potential to help navigate the technical challenges of operating an electricity system in transition.

3.2.1 Electricity production

Electricity is the ultimate example of a "just in time" delivery service. Electricity generation must exactly match electricity demand in real time. This balance can be achieved by controlling either electricity supply and/or demand. While historically the focus has been on controlling generation, there is a growing recognition that controlling demand can be highly advantageous and presents a largely untapped opportunity.

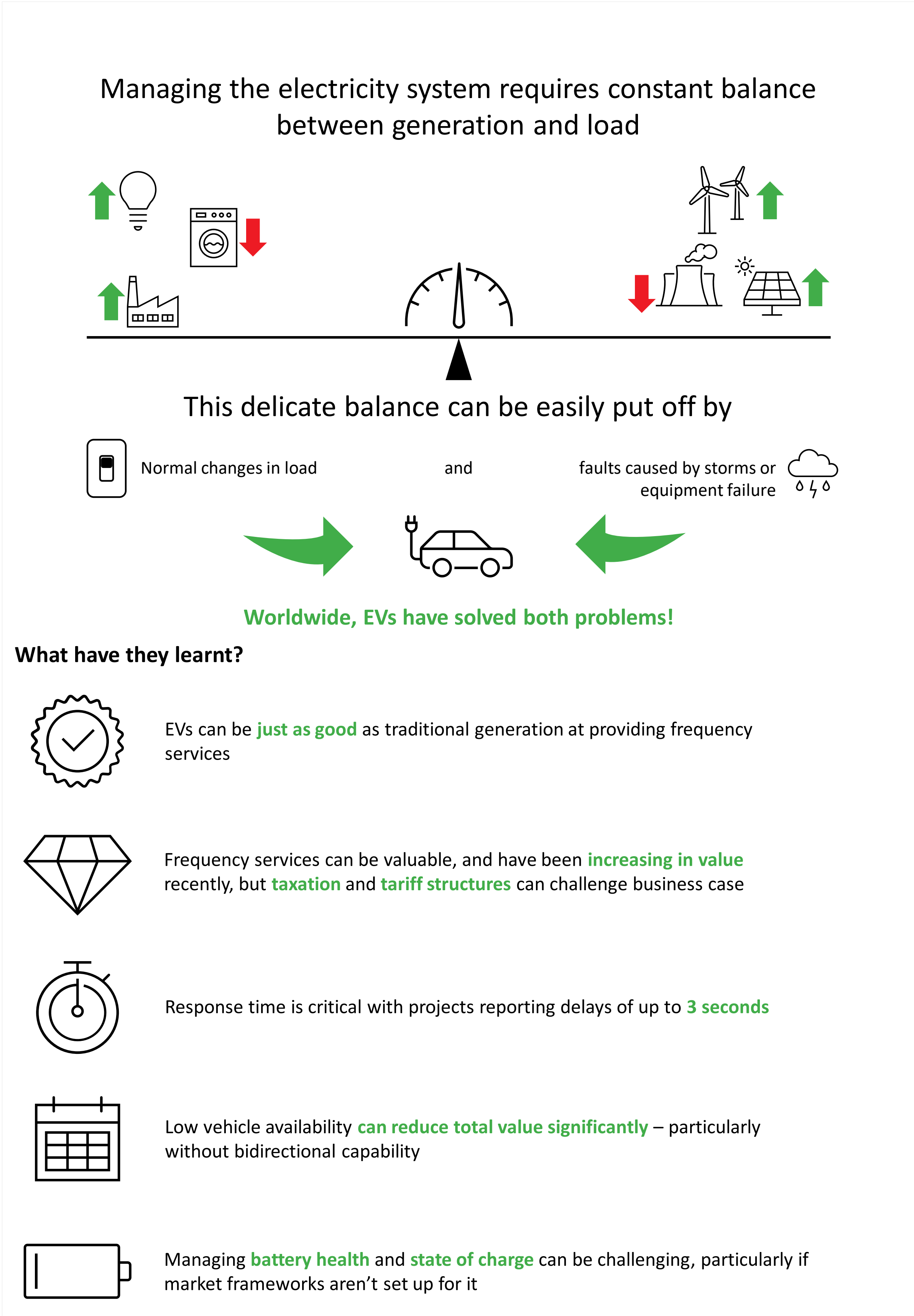

Figure 9: Managing an electricity system with the help of V2G.

In addition to the ongoing balancing of supply and demand, the electricity system also holds significant amounts of quick access generation in reserve to cover unexpected contingency events. This is essential to ensure the very high degrees of reliability that society expects.

Because EVs are quite flexible in how they charge and contain significant reserves of fast to access energy in their batteries they are well suited to contributing to balancing supply and demand in the electricity system. They can contribute to both the ongoing balancing of dispatched electricity with demand and in the emergency management of contingencies.

Balancing energy production with consumption

A foundational task in managing an electricity system is planning how to balance anticipated energy generation and demand. This is typically addressed with a rolling 24-hour time horizon and is therefore referred to as "intra-day" balancing. Such planning ensures:

- that sufficient generation is online to meet load and expected contingencies,
- that generation patterns and electrical flows are "secure" meaning that they do not overload parts of the electrical network and can withstand disturbances to the network such as knocked down power lines, and
- that dispatchable generators are used in a way that meets the goals of the energy system e.g. lowest cost or highest renewable penetration.

This report considers two aspects of how EVs participate in intra-day balancing:

1. how can EV charging contribute to meeting a desired outcome (such as increasing the utilisation of renewable energy generation), and
2. how these services are valued in electricity markets.

Controlling EV charging to assist intra-day balancing

Recent additions of renewable energy generators whose output varies due to resource availability have made markets more volatile. Similarly, customers may have a preference for renewable over fossil-fuel energy, depending on their values [61]. This is particularly true for customers who have their own renewable generation such as solar PV [62]. EV charging is a flexible demand, and in the case of V2G, can act as a generator. They can actively alter their power flow to maintain balance.

Smart charger and intelligent energy management systems can help integrate renewable energy [22, 63]. Similarly, EVs increase system demand, but their flexibility means that any additional generation required to supply them could be renewable [64-67]. Figure 10 shows an example of EV charging coordinated to meet solar generation.

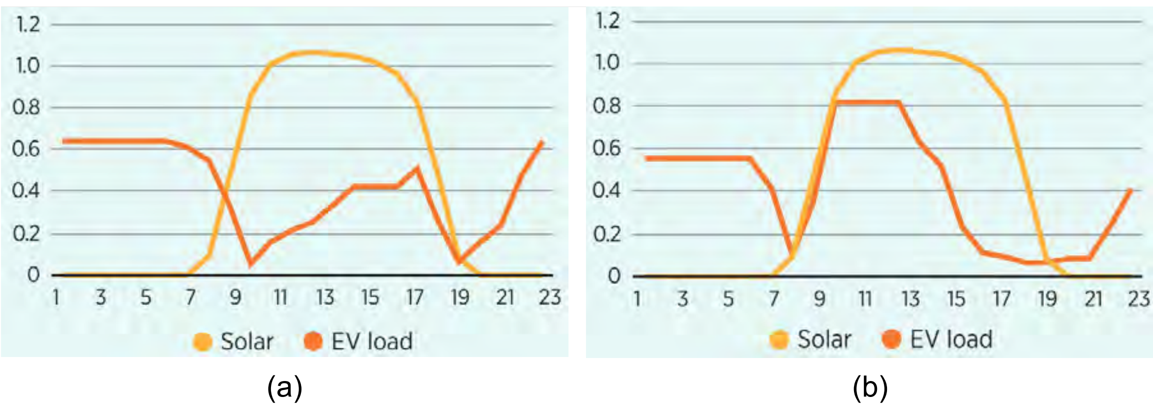

Figure 10: EV charging with PV systems (a) uncoordinated (b) coordinated charging [68]. Reproduced with permission of the copyright holder.

Julia et al. from the University of California, Berkeley conducted a detailed analysis of a renewable energy production and curtailment scenario in 2025. It showed appropriate EV charging strategy and adoption levels could reduce renewable curtailment by 9%–40%, or about 120–410 GWh for the case with 0.95 to 5 million EVs, as shown in Figure 11.

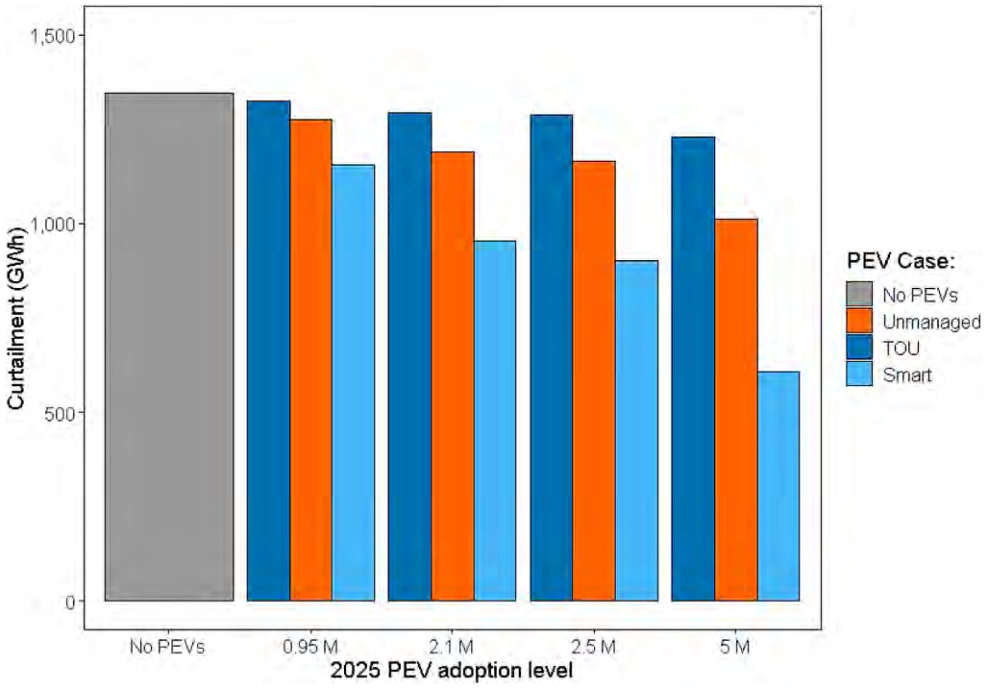

Figure 11: Annual RE curtailment in California in 2025 scenario for various charging strategy and EV adoption level [69]. Licensed under Creative Commons.

This study also showed the dangers of uncoordinated pricing signals. Time-of-use (TOU) charging can increase renewable curtailment if pricing signals and renewable generation output do not correlate. This issue was apparent in the BMW and PG&E ChargeForward project. This demonstrated managed EV charging and "second life" EV batteries participating in the Californian "day ahead" and "real time energy" markets [70]. In use EV availability during events was highly variable. On average 80% of the demand response came from the "second use" battery while 20% came from the EVs, but the contribution was highly variable between 0% and 70%. Each participating vehicle provided 4.4kW of capacity but only 7 of 100 vehicles were available to provide demand response on average for each event. This means vehicles only provided 0.2kW of capacity each on average. The low EV participation rate was related to several factors:

- Average charge length was relatively short (around 3 hours)
- 60% of participants were on a time of use tariff that incentivised drivers to charge after 11 PM, while most events were called between 8 and 9 PM [70].

In areas with a high solar PV uptake, there are moves to encourage demand at peak generation times. An example of this is South Australian Power Networks "solar sponge" tariff, which provides a low-cost period during times of peak solar generation [69]. Similarly, Western Power's "100MW challenge" aims to increase demand during peak solar times to allow more renewable generation.

Valuing services through markets

In most jurisdictions intra-day balancing is implemented via a market. These markets aim to facilitate generators selling their electricity to consumers in a way that minimises consumers' costs [71]. Because these markets tend to be highly volatile most customers do not engage with them directly, instead procuring their energy from an energy retailer who manages the market volatility and offers customers a fixed price. This means that retailers are acutely focused on managing the gap between their exposure to market volatility and their fixed contracts with their customers [72].

Traditionally retailers managed their exposure through hedging contracts with generators [73]. In a recent development such financial hedging has been complemented through physical hedging using energy storage. This has, for example, been demonstrated by The University of Queensland using a 1.1MW/2.15MWh battery [74]. V2G EVs may offer a similar physical hedging service.

Another recent development is the emergence of retailer offers that do pass market pricing through to customers [75, 76]. One of these, Octopus Energy's 'Agile Octopus' product in the UK, has shown that EV drivers are highly responsive to real time pricing, with drivers reducing their peak time energy consumption by 47%. EV drivers who participated in this product saved £132 ($238 AUD) per year compared to Octopus' standard tariff [77].

Mapping a response similar to the Octopus Energy tariff on the Australian market price gives an indication of how dynamic pricing may reduce costs for energy retailers. Figure 12 shows the average and variance of Victorian energy prices mapped on the average charge profiles experienced by Octopus Power with and without their dynamic pricing product [77, 78], and a simple naïve optimisation algorithm[1].

[1] Perfectly flexible charging during lowest price periods 11PM-7AM, 3.6kW EV charger, perfect price foresight. This algorithm is unlikely to be credible in a real-world application but indicates a maximum threshold for benefit.

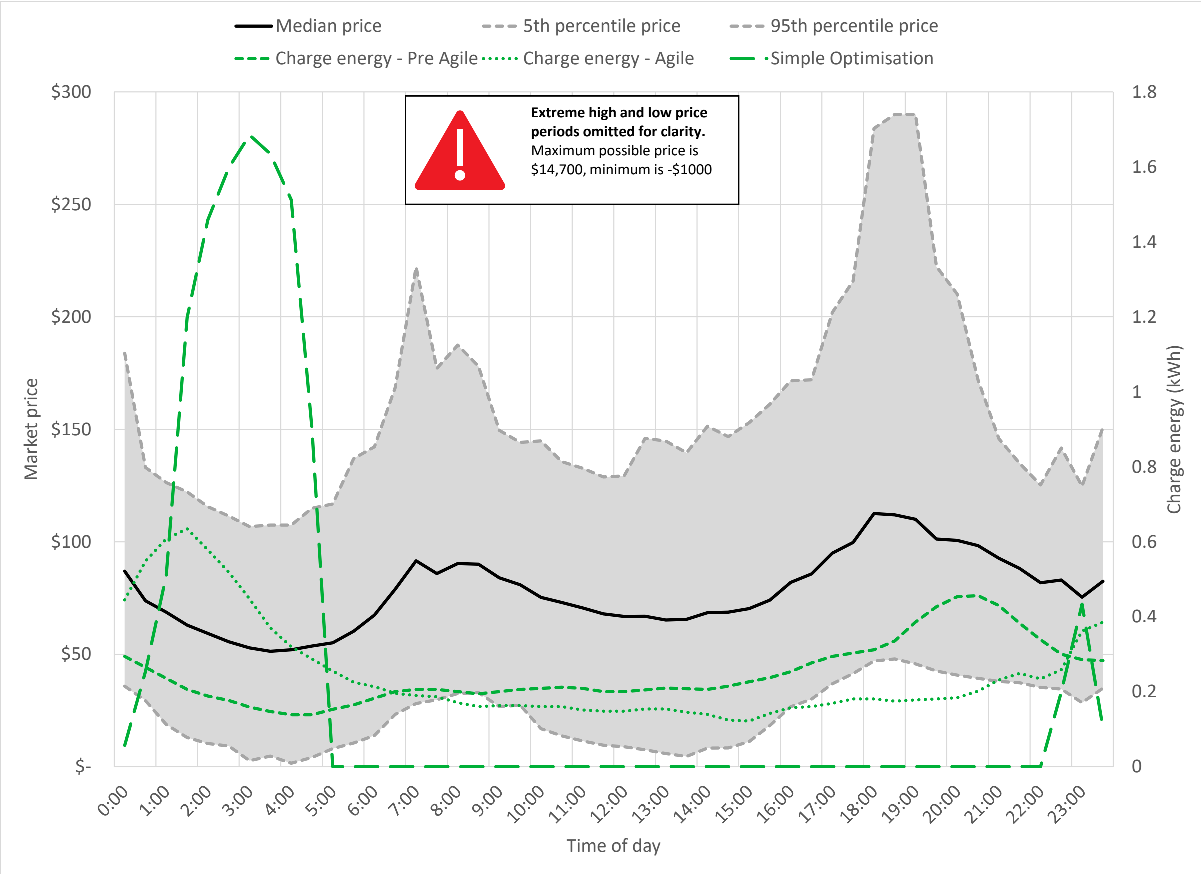

Figure 12: Charge energy from Octopus UK trial and Australian energy prices

These algorithms show a reduction in total charge cost as shown in Figure 13. Perfect optimisation shows a nearly 50% reduction in total charge costs. The periods of charging for simple optimisation are generally midnight to 5AM, which maps closely to existing EV specific pricing products such as the Powershop "super off-peak" pricing window of midnight to 4AM [79].

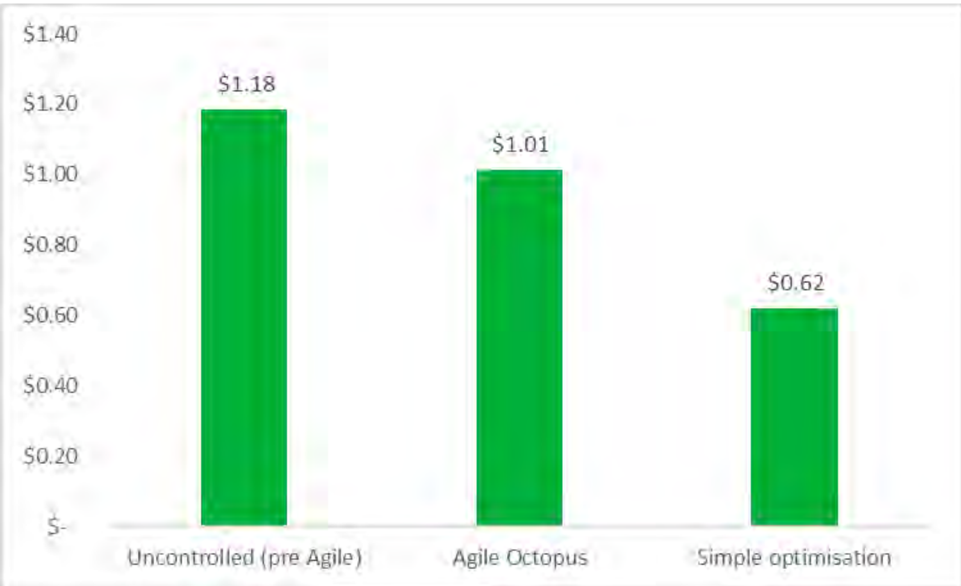

Figure 13: Average daily charge cost for charging profiles

Average costs like those described above hide the volatility of energy pricing. Between 1/6/2018 and 23/06/2020 there were three standout days that contributed significantly to total energy costs, as shown in Figure 14. These pricing peaks were all caused by extreme temperatures [80-82], which suggests that mitigating exposures to such extreme events will be increasingly important as global warming continues to amplify the frequency and severity of extreme weather events.

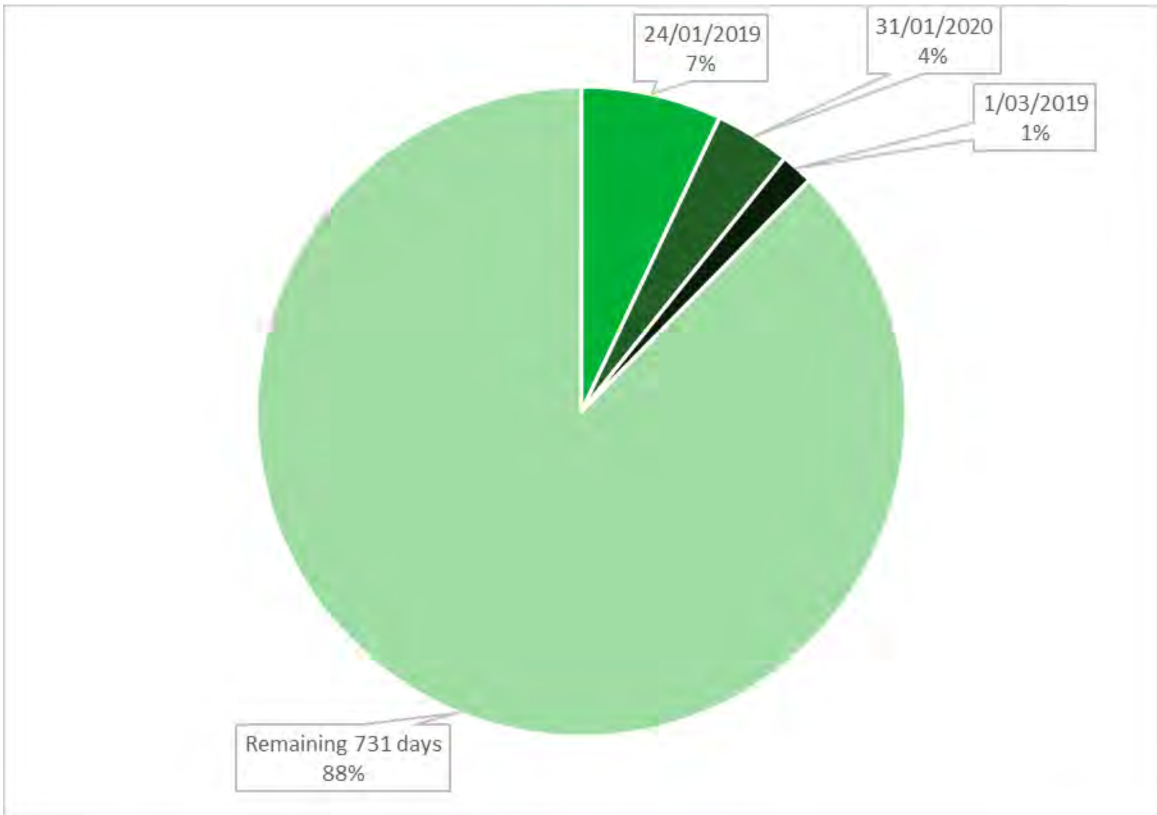

Figure 14: High charge cost days

With appropriate market frameworks, EVs can provide market benefits without active retailer involvement. In this case other market participants (Energy Services Companies) operate in energy markets and pass the benefits on to customers. In California energy services companies can participate in the energy market providing energy and ancillary services [83]. The Enel-X "JuicePlan" EV charging plan is an example of this. This plan provides customers with a smart V1G charger and access to their optimisation app for $19/month ($28 AUD) [84]. This plan includes a JuiceBox 40 EV V1G charger ($599 US/$871 AU separately) and installation. The JuicePlan requires that customers appoint Enel-X as demand response provider, curtailment service provider, or aggregator to enable participation in demand response markets. Customers who purchase a compatible charger separately can participate and get paid JuicePoints instead (1,000 JuicePoints=$1 US/$1.45 AUD) [85].

In rare cases the market may fail to adequately provide enough capacity to operate the power system securely. This might be due to extreme temperatures, plant failure, or natural disasters. In Australia the energy market operator, AEMO, can procure services for this function using the Reliability and Emergency Reserve Trader (RERT) function. This allows AEMO to create bilateral contracts for demand reduction or generation increase that can be used during emergencies [86]. Participation in RERT requires reserves that are not available through other means, which would preclude EV chargers providing other energy-related services. Currently RERT services are procured through a tender run before each summer. In 2018 AEMO secured 1,150MW of services [87]. The costs for RERT contracts are recovered from load customers. Providers of RERT services are not permitted to offer the same capacity into energy markets (i.e. it must be capacity that cannot be procured through other means). V2G EV chargers may be able to provide this service when they are plugged in and ready during events.

Managing frequency

While balancing services are dispatched to meet expected demand, there are invariably minor mismatches between forecast supply and demand and actual supply and demand. This mismatch is quantified by monitoring the frequency of the AC electricity. Each electrical system is designed to operate at a nominal frequency – in Australia this is 50 Hz. When supply matches demand, this is what the frequency is. When, on the other hand, mismatches occur, the frequency deviates from nominal. If demand exceeds supply the frequency declines, while if supply exceeds demand the frequency increases.

Supply/demand imbalance occur due to two distinct causes:

- Forecasts invariably have some error due to natural variations in generation and load, causing small variations in frequency, and
- Faults may cause the large amounts of load or generation to disconnect, causing large variations in frequency.

Managing the security of electrical systems is primarily about monitoring and responding to deviations in frequency, both minor and mundane, and large and urgent.

These are managed economically and technically in a power system with three key services:

- Inertia services that act to slow the rate of change of frequency
- Regulation services that act to manage normal variations in load and generation
- Contingency services that manage faults.

How these services work together to manage frequency is shown in Figure 15.

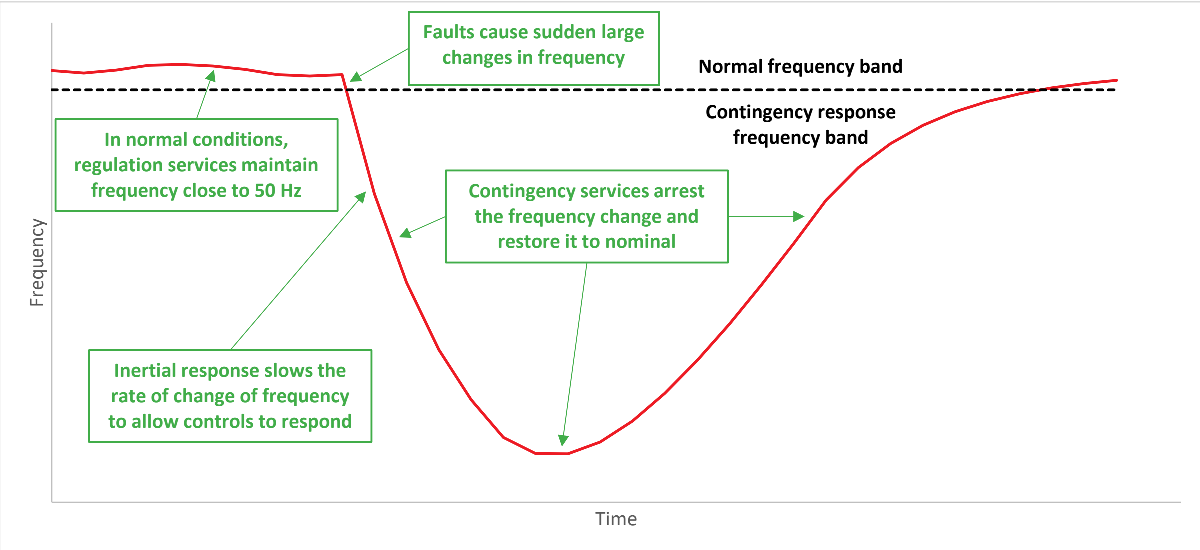

Figure 15: Frequency response

Maintaining good control of frequency is particularly challenging when transitioning electrical systems from those primarily driven by synchronous generators (like coal fired power stations) to those largely driven by asynchronous generators like power electronics governed solar and wind generators. This difficulty arises due to the fundamental physical difference in how these generators interact with the frequency. Synchronous generators have a rigid fixed physical relationship between their behaviour and the frequency (governed by the physical inertia of masses spinning within their generators), whereas asynchronous generators have a dynamic relationship that can be quite freely designed in their control system. The difficulty in managing this transition is often reflected in increases in the prices of frequency control services traded on a market. See Appendix E for more details [88].

The REVS project involves a demonstration of frequency control from V2G-equipped electric vehicles. How it provides these services is shown in Figure 16. This is backed by significant research and demonstration in other parts of the world [66, 67, 89-93].

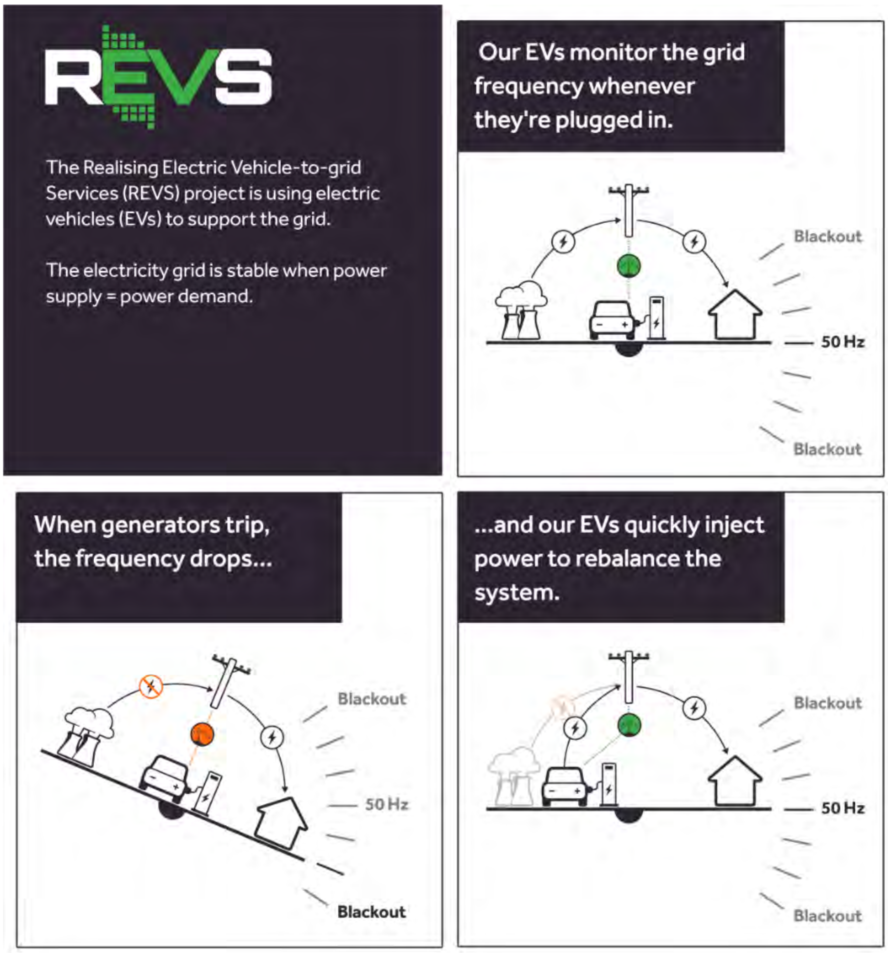

Figure 16: REVS project provision of frequency control services

Frequency control is usually provided by local controls because these can respond with the necessary speed. These can be divided into two types:

- Controls that act based on frequency and provide regulation and contingency services, and
- Controls that act based on rate of change of frequency and provide inertia type services.

V2G equipped EVs can provide both of these services. Rezkalla et al. compared both control types through simulations and experiments and found that inertia-based control is more complex and challenging to implement in the real world [67]. While proper deployment of inertia control may provide better frequency performance, regulation and fast frequency response services are simpler to implement and provide acceptable performance. These services can have significant value as well. A study of the prospective value of frequency control provision of V2G EVs in the PJM market showed a ten year Net Present Value (NPV) of $20,000 for regulation services and $5,000 for contingency services for a 10kW EV charger [94].

EVs must provide frequency control services within state of charge constraints. This is required to ensure vehicles can also provide the required transportation services. Izadkhast et al suggested an aggregate model of EVs to manage this [95]. They used a participation factor to enable incorporation of several EV fleet characteristics such as minimum state of charge (SoC) required, power limitations, and constant current and voltage charging. The performance of the proposed method was validated in a Spanish power system. Figure 17 shows the system frequency response with and without EV participation. The participation of the EVs in frequency regulation significantly improved the system performance due to the fast response of the EV battery and charger systems.

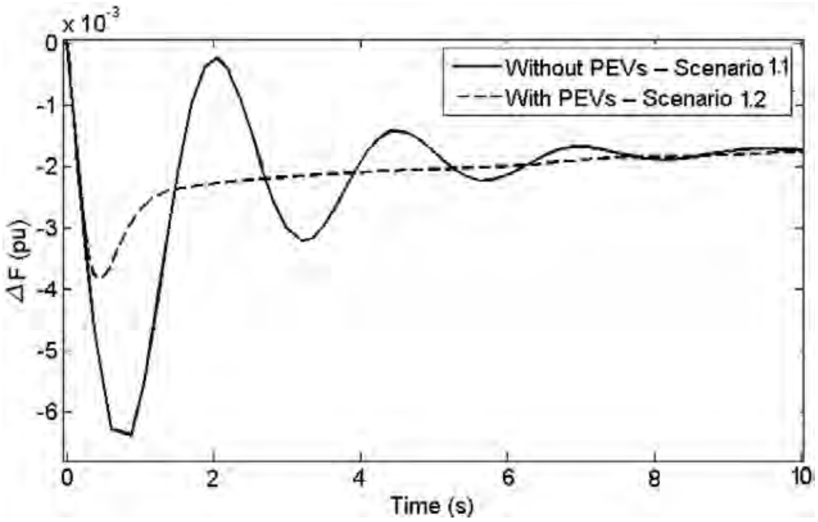

Figure 17: System frequency response with and without EV participation [95]. Reproduced with permission from the copyright holder.

The Parker project in Denmark was a real-world demonstration of both regulation and contingency frequency services [96, 97]. This project showed that V2G-equipped EVs can provide frequency services, as shown in Figure 18. While the regulation operated as expected there was a three second delay between the power target being issued and the EV chargers responding. This may be caused by delays in charger power electronics, measurement and communication delays, or physical and technical constraints of the equipment, such as the current steps of the charger. This project also showed the economic challenges of realising the value of V2G for frequency service. The difference between consumption tariffs and frequency control prices and taxation on energy led to the service being unprofitable based on current rules. Even without the tax payable on energy consumption the service at most breaks even [98].

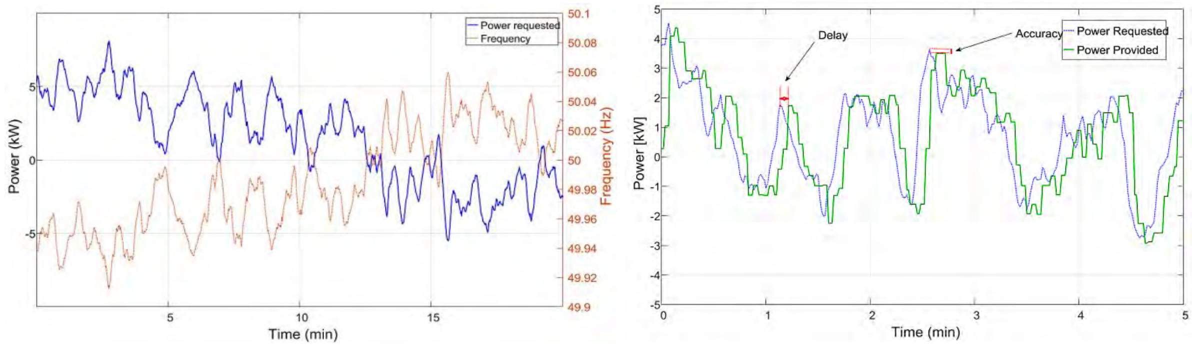

Figure 18: Requested and provided power in Parker project [97]. Reproduced with permission from the copyright holder.

In contrast, the University of Delaware showed V2G EVs can provide a better regulation service than traditional synchronous generators because they can respond more quickly. This is shown in Figure 19, where the regulation signal is based on the systems overall needs, scaled to the EV's power capacity [94]. This project also showed that this service may drain the EV battery excessively, impacting the utility and battery health of the vehicle.

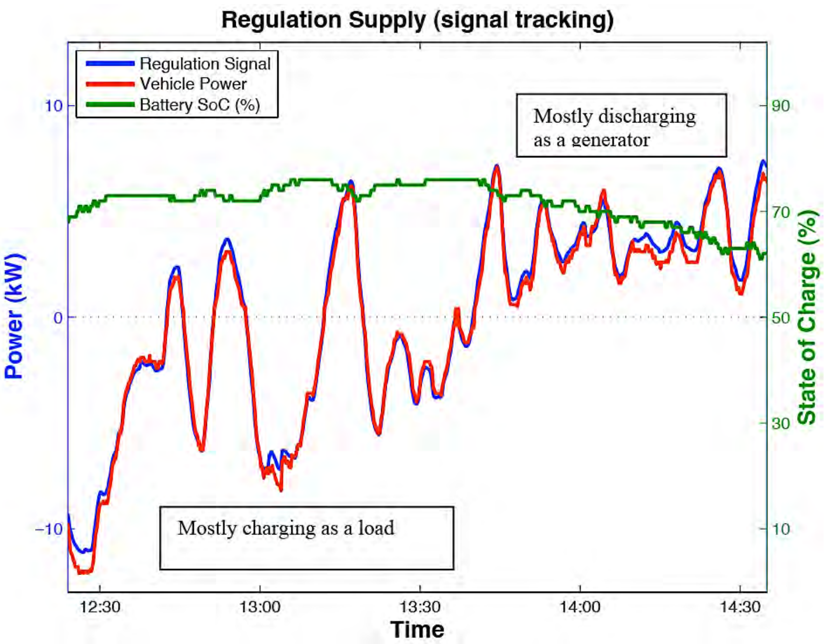

Figure 19: Regulation frequency raise and lower services in University of Delaware V2G project [94].

In Australia Frequency Control Ancillary Services (FCAS) is traded across eight markets, as described in Table 8. Generally, services that raise the frequency are higher value than services that lower the frequency. This is because it is easier to reduce a generator's output than increase it. Similarly, shorter time contingency bands are worth more due to the difficulties in responding to events quickly. Energy consumers (and retailers on their behalf) are required to pay for contingency 'lower services', and generators pay for 'raise services' under the 'causer pays' methodology.

Inertia services are not traded on a market in Australia. Instead transmission network service providers are required to maintain fault level and inertia in their networks to a level set by the market operator [88]. If a shortfall is identified, networks procure services via network investment or bilateral contracts with service providers. There are examples larger inverters such as wind turbines or batteries providing inertia services to the grid in Australia [99]. The cost of these services are recovered in transmission charges.

Table 8: Frequency control markets in the NEM

Time domain	Market	Type	Average Price (VIC 06/18 – 06/20)
0-6s	Fast Raise	Contingency	$11.65
	Fast Lower	Contingency	$0.46
6-60s	Slow Raise	Contingency	$8.30
	Slow Lower	Contingency	$0.23
60s-5m	Delayed Raise	Contingency	$7.67
	Delayed Lower	Contingency	$0.36
Regulation	Regulation raise	Regulation	$33.89
	Regulation Lower	Regulation	$15.06

The value that could be realised from V2G frequency control depends on the probability the vehicle is plugged in, its current power setpoint, and the co-incident market price. The average price of FCAS services over a day is shown in Figure 20. 'Raise services' value changes throughout the day and follow the profile of energy prices, while 'lower service' prices are largely invariant throughout the day.

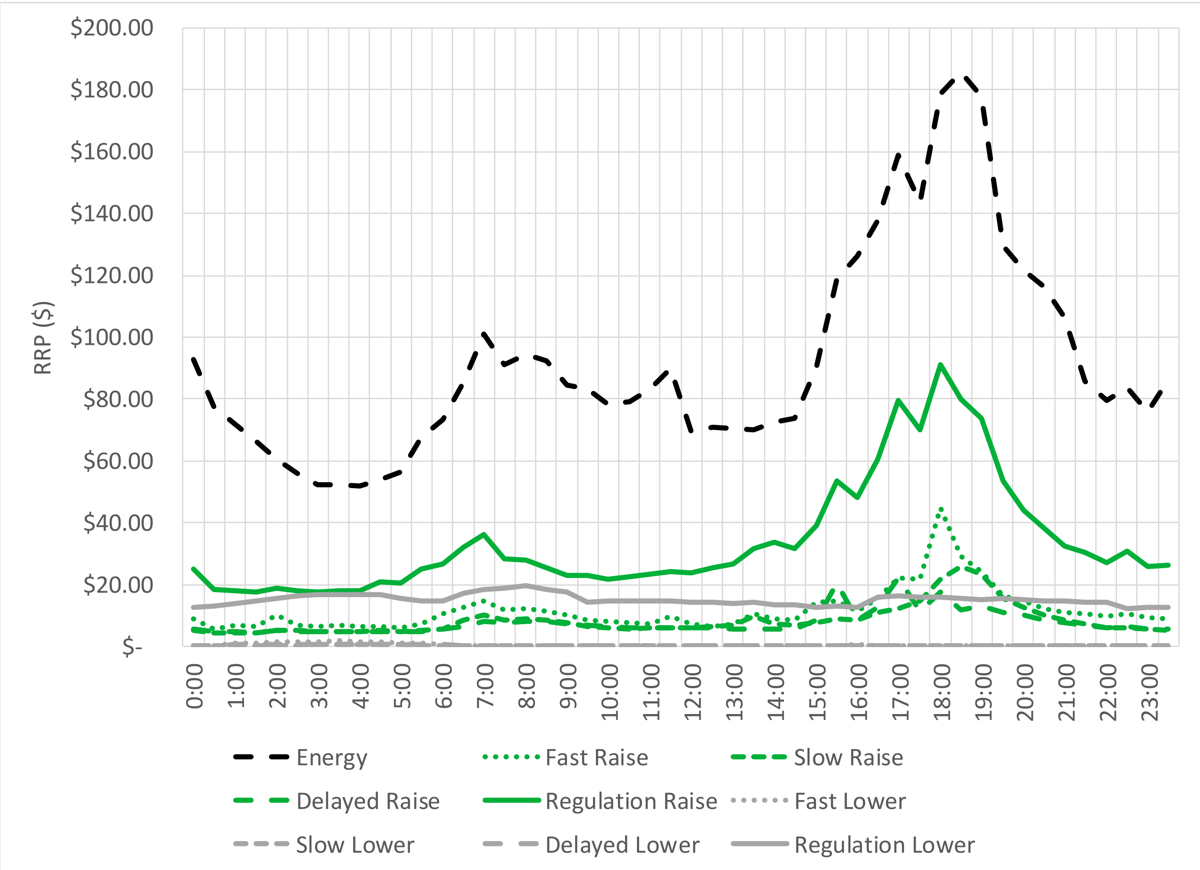

Figure 20: Average prices of FCAS services 2018-2020

The Los Angeles air force base V2G project demonstrated the impact vehicle availability can have. In this project 29 vehicles with a combined battery capacity of 859 kWh provided grid services, however in practice only 100-400 kWh was available. Calculated available MWh for frequency support is shown in Figure 21. The low availability was a symptom of both vehicle availability and charger faults.

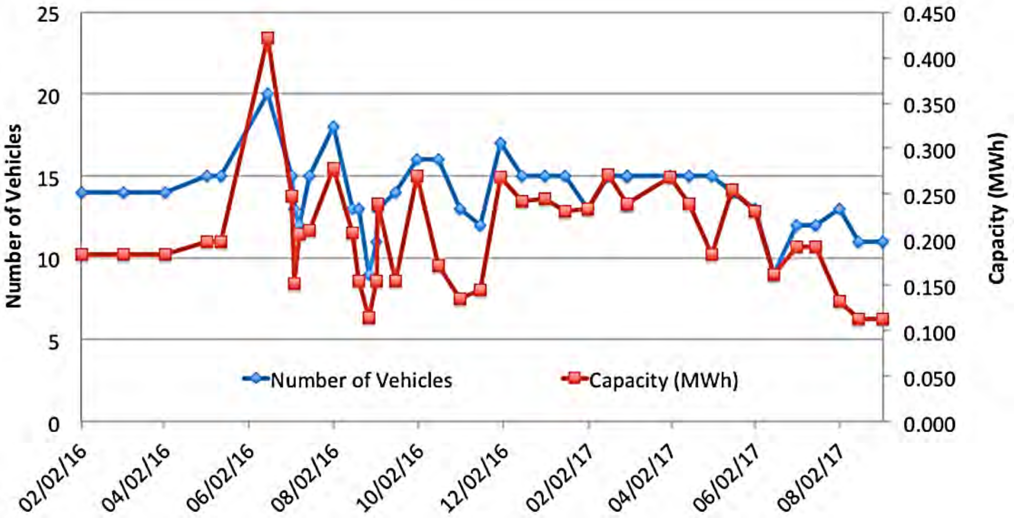

Figure 21: Available vehicles and equivalent reserve capacity in Los Angeles air force base V2G demonstration project [100].

During extreme events there may not be enough frequency control services dispatched via the market to maintain system security. Emergency Frequency Response is *"the last line of defence to protect the power system and prevent major blackouts from occurring due to sudden system disturbances"* [101]. Traditionally this service has been provided by circuit breakers shedding load or generation. Its operation can cause power outages for customers. In the Australian market customers whose peak demand exceeds 10MW are required to provide 60% of their expected demand as under-frequency load shedding [101]. EVs, particularly if equipped with V2G chargers, may provide emergency frequency response. One desktop simulation showed that V2G EVs providing frequency control had the potential to reduce under-frequency load shedding by 90% in a simplified power system [102].

Relatively small sources of FCAS can significantly alter pricing outcomes. Hornsdale Power Reserve (HPR) is a 100MW/129MWh centralised battery in South Australia. This battery is equivalent to around 14,300 EVs of similar capacity to those used in REVs. In 2019 it captured 15% and 12% of the volume in the contingency and regulation FCAS markets respectively. Its service reduced total FCAS costs for $80m and $36m in the contingency and regulation FCAS markets respectively [103]. This can clearly be seen in the price outcomes for FCAS in South Australia, as shown in Figure 22. This is also a risk for aggregators who may require high prices to achieve a sufficient return on their investment. This is discussed further in 4.2.1 and Appendix E.

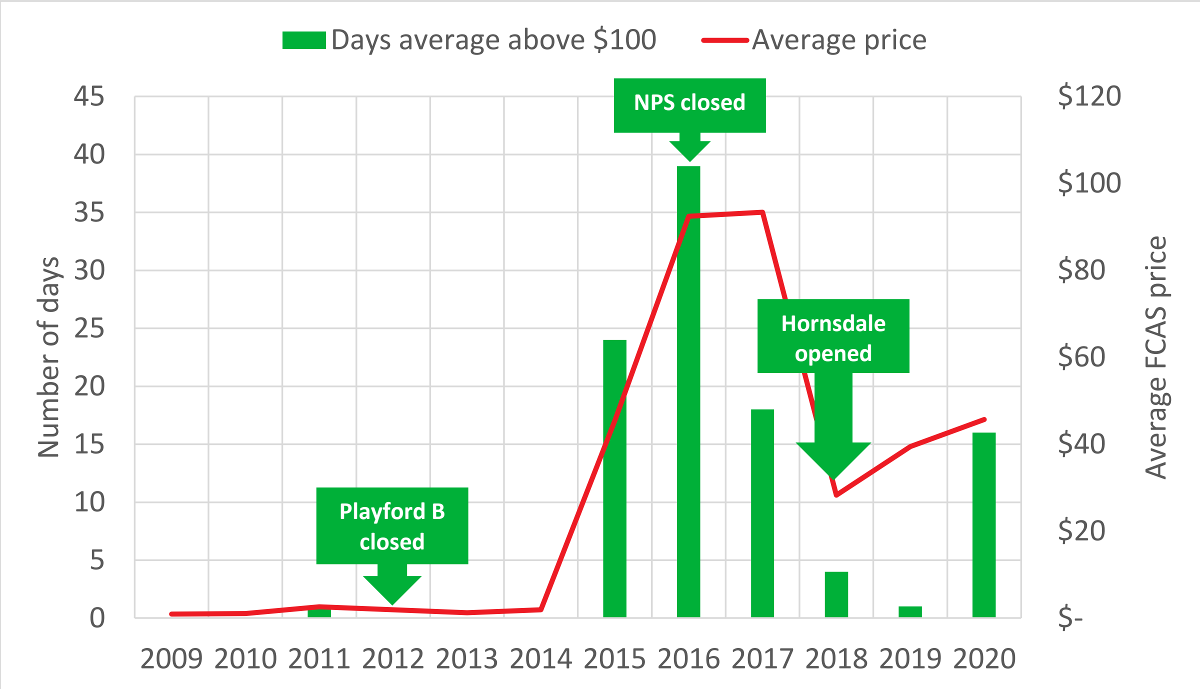

Figure 22: Frequency Control Ancillary Services prices in SA

3.2.2 Electricity delivery

In order to serve the needs of customers, power that is produced off-site must be delivered to customer's premises. This requires the power to flow through the wires, transformers and other components of the transmission and distribution networks. These components have fundamental physical limits, which are typically set by voltage levels and/or limits to the amount of current that can be sustained before over heating (thermal limits).

This report focuses on how EVs can benefit both technical and economic aspects of electricity delivery in the following domains.

- Congestion management – physical limits of network components
- Power quality – voltage control, harmonics and power factor
- Security of the networks – system strength
- Data and demand forecasting – network planning and operation

Congestion management

Congestion can occur when networks do not have sufficient capacity to transport the desired electricity to the consumer. This is because the components that make up networks have physical limits to the electricity they can carry. Congestion management is used to efficiently manage the network without violating constraints. There are several methods by which the congestion can be managed, such as demand management, generator rescheduling, modifying the network topology, or installation of conventional compensation devices such as flexible AC transmission system devices, etc.

EV chargers are the largest single load in most customer houses. They have the potential to increase peak demand and hence congestion on the network significantly. The "My Electric Avenue" project in the UK aimed to investigate the impact of clusters of EV chargers on network congestion [104]. This project involved 200 EVs in the southern UK, 100 of which were in single street clusters of around ten. This project showed that unmanaged EV charging has the potential to double localised peak demand, as shown in Figure 23. Importantly, this trial used older generation Nissan Leaf vehicles with relatively small 3.3kW inbuilt chargers. Modern EVs commonly charge at double this rate. Even with 3.3kW chargers this report showed that congestion begins at around 50% EV penetration on a local network. It predicted that if charging were unmanaged 32% of LV feeders across Britain would need reinforcement by 2050. This however could be mitigated by managing charging.

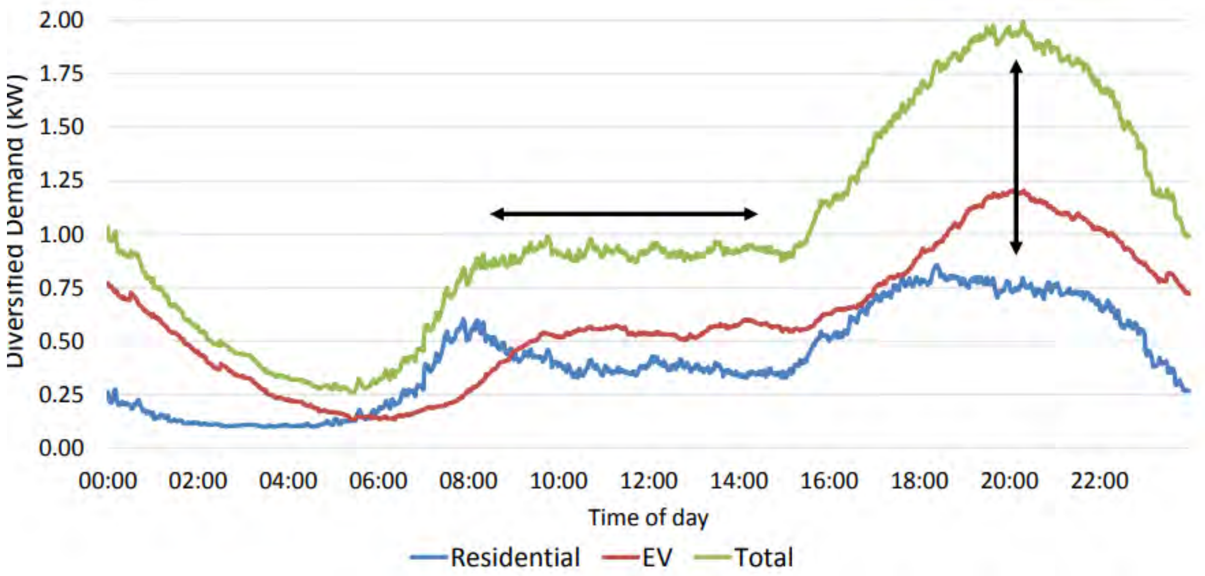

Figure 23: Peak demand increase due to unmanaged EV charging [104]. Reproduced with permission from the copyright holder.

The “My Electric Avenue” project demonstrated that managing charging could avoid network reinforcement. The next sections build upon this to discuss how smart charging of EVs and the V2G technology can manage network demand and defer transmission and distribution investment. It will also indicate the value of these services.

Demand management – peak shaving and load shifting

Peak shaving and load shifting refers to the levelling-out of peaks in electricity demand by shifting some loads to off-peak periods. The objective is to avoid investment in generators or networks to supply peak demand. Peak demand occurs rarely, leaving these assets underutilised. Much research has been, and continues to be, conducted on effectively managing peak demand [105-107].

The “Electric Nation” project in the UK showed EV charging is flexible and can be shifted to avoid network peaks. Figure 24 illustrates how flexible[2] charging is throughout a typical weekday during this project. Peak flexibility coincides well with evening peaks meaning demand management is a highly effective tool to manage evening peaks [108].

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[2] Defined as the ratio of time the charger is idle during the time it is plugged in:

$$flexibility = 1 - \frac{charge\ duration}{plug\ in\ duration}$$

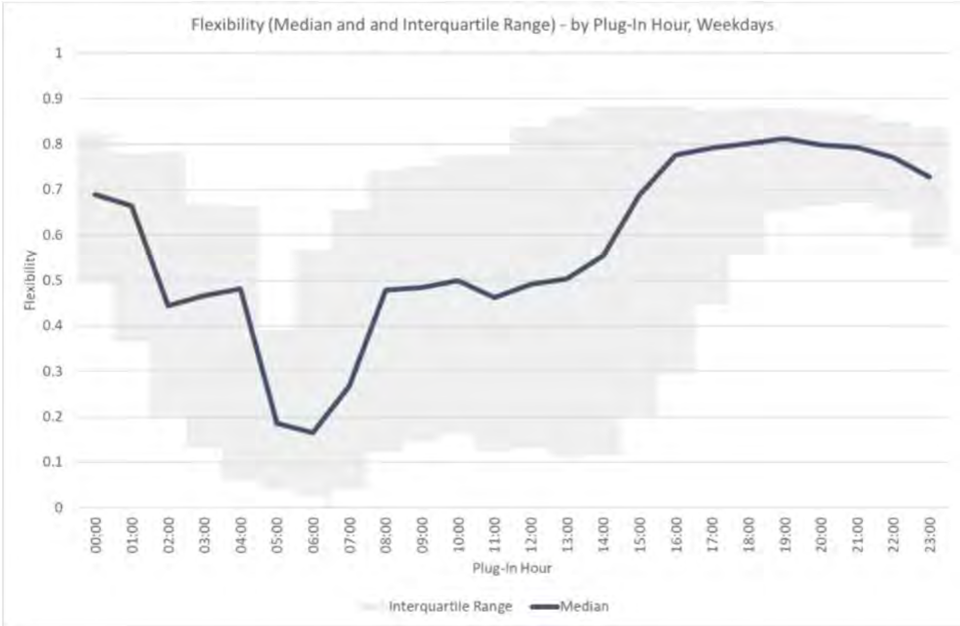


Figure 24: Flexibility - Median Value and Interquartile Range – Weekdays [108]. Reproduced with permission from the copyright holder.

The EVs have the potential to reduce network prices if managed appropriately. A recent study by EvEnergi on the South Australian network stated *"If managed correctly, EVs could potentially improve network asset utilisation"* [109]. This is through increasing energy throughput at off-peak times and increasing demand at times when there is excess renewable generation. This could be achieved though network pricing. Distribution network pricing has traditionally been based on volumetric energy (kWh), however more cost reflective pricing through demand (time of use or flat), time-of-use energy, or fixed charges [34] can resolve this. The aim of cost reflective prices is to ensure:

- In the short term, the system is operated efficiently
- In the long term, it promotes the path of least-cost development [35]

Energy retailers are often responsible for recovering transmission or distribution network charges [110, 111]. In some jurisdictions retailers are separate from networks and system operators (UK, NZ, AU). In others vertical integration between levels (particularly generation, distribution, and retail) is more common (US, Canada). Retailers can choose how network pricing is presented to customers [34]. The most common way of presenting cost-reflective prices to customers is through a time-of-use consumption tariff. There are many examples of these. One source stated that in the US alone in 2017, there were over 25 utilities offering special electric car tariffs [112]. Austin Energy have two projects that have addressed network pricing with EVs or a combined Distributed Energy Resources (DER) solution. Their EV trial created a "free energy" off-peak tariff for EV charging. It successfully moved virtually all EV charging outside times which would cause transmission pricing impacts [113]. Their SHINES project, while not focused on EVs, investigated utility peak load reduction from aggregated customer-sited DER. This project showed that "*in the ERCOT market, the value of reduced transmission cost of service realized through the utility peak load reduction application far outweighs the economic value realized by the day-ahead energy arbitrage and real-time price dispatch applications combined [108]".*

EVs are potentially a means to manage constraints in distribution networks introduced by PV uptake. One example of this is SA power networks' "Solar Sponge" tariff. This tariff offers a low-cost period in the middle of the day aimed at increasing demand to absorb excess solar. The off-peak rate is 25% of the standard single rate tariff and applies from 10AM-3PM [69]. This provides customers with a strong price signal to schedule charging at high solar generation times. Similarly, Western Power's "100MW challenge" aims to increase demand at times of high solar generation [86]. Additionally real-time price-based methods may be a tool to effectively manage the demand induced by large amounts of rooftop PV [114]. Octopus energy (UK based retailer) introduced real-time based tariff "Agile Octopus" in 2018. This product provides customers with a 30-minute dynamic price for the day ahead at 4PM each day. Customers can then choose when to consume energy to minimise their costs [115]. They have found that customers with EVs are more sensitive to the price signals. Octopus agile response from EV customers are shown in Figure 25. Most active Agile customers with EVs reduced peak electricity consumption by 47%, saving each an average of £132 ($237 AUD).

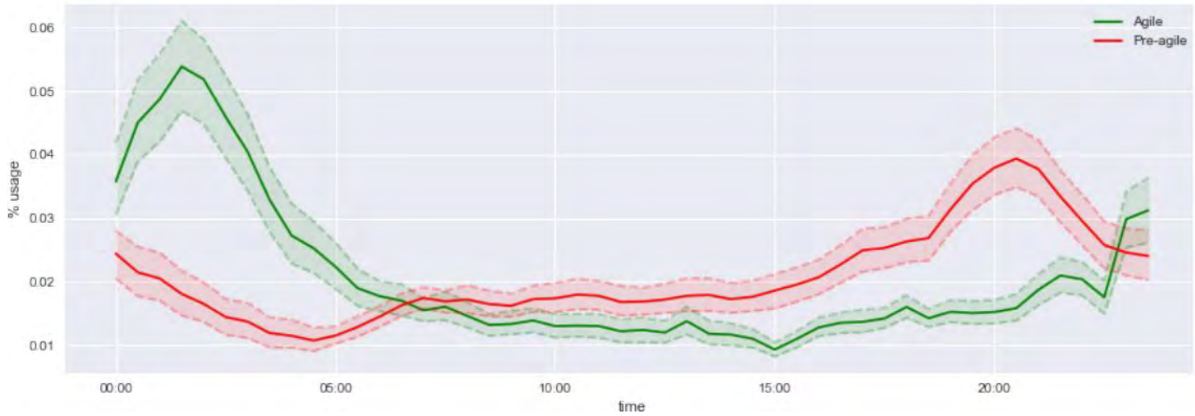


Figure 25: Octopus Agile response from EV customers [115]. Reproduced with permission from the copyright holder.

V2G capable EVs add an additional dimension to charge control. They are being promoted for dealing with the peak demand especially when combined with renewable generation. A V2B demonstration project led by the University of California, Los Angeles (UCLA) demonstrated a smart charging algorithm is capable to shift peak load by scheduling power flows in 30 EVs, as shown in Figure 26 [106, 116]. The plotted data were collected on 20 September 2016 from 7am to 7pm, and the 12-hour data were split into 60 time slots for the purpose of better demonstration. The smart algorithm and bi-directional charger flattened the original base load curve by shaving the peak at approximately 30%.

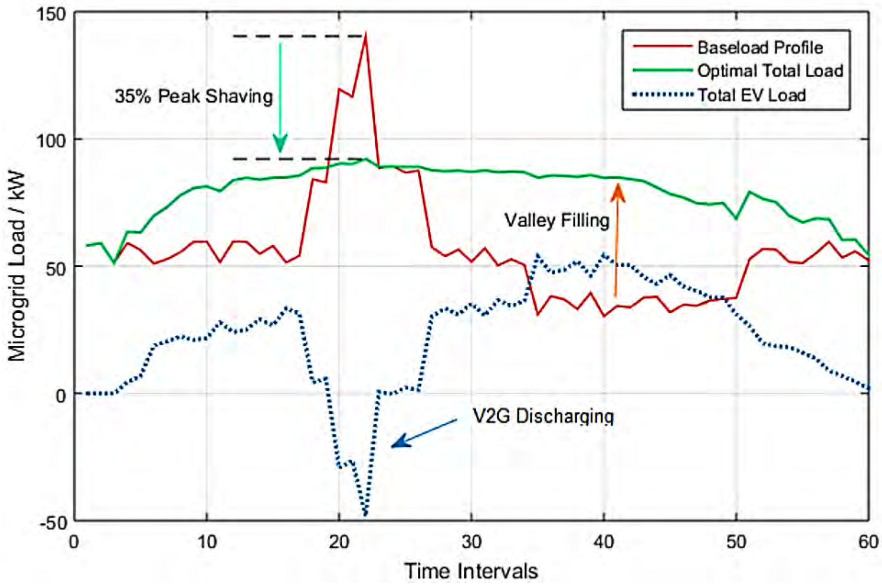


Figure 26: Peak load shifting and valley filling demonstrated in the UCLA V2G project [116].

The first Australian V2G trial was undertaken by AusNet Services in collaboration with the CSIRO in the summer of 2013/14 [117]. The key objective of this trial was to examine the potential of V2G in reducing peak demand. One Toyota Prius hybrid vehicle was converted to plug-in EV by installing larger lithium-ion battery (11.8 kWh) and then related controls and software were deployed to make it V2G capable. The maximum discharge rate of the vehicle was 1.1 kW. During the trial, the vehicle was regularly plugged-in in the evening when the customer returned home after their daily commute. This coincided well with AusNet's peak demand during summer evenings due to residential air conditioning. The customers load profile is shown in Figure 27, where the dashed line shows the effects of V2G. Even after driving approximately 33 km and with the relatively small battery, there was enough charge to provide an average of 1.9 kWh energy to the home. This discharge resulted in a significant reduction of the customer's peak demand.

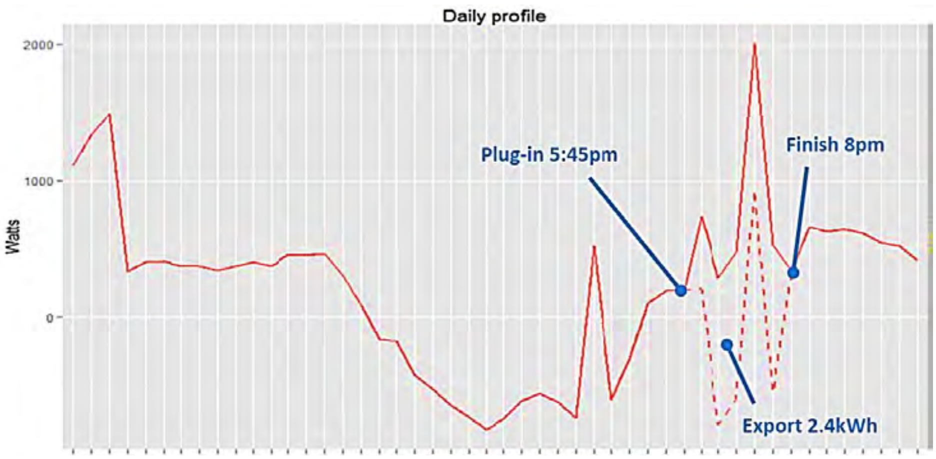


Figure 27: Effects of V2G on customer's load profile in typical summer day [93]. Reproduced with permission from the copyright owner.

Feed-in tariffs can signal congestion to V2G EV owners. Project Scurius in the UK aims to create a resource of 1,000 V2G EVs participating in the UK's "piclo" demand response market.

Participating customers receive a free V2G EV charger, as well as being paid 30p/kWh ($0.54/kWh AU) for energy they discharge from their EVs, totalling up to £500/year ($895 AUD). Customers with solar generation receive a slightly lower feed in tariff of 26p/kWh ($0.47 AU) [118].

Deferral of network investment

EV charge and discharge management may defer or entirely avoid investment in transmission and distribution assets such as power lines and transformers. This can reduce network charges for all connected customers [119, 120].

V2G services are in many cases well suited to deferring network investment because network overload events are, at least initially, infrequent and comparatively small [22]. Such events can therefore be managed using only a limited amount of controllable energy within the network. Demand response solutions, such as V2G, are particularly attractive because they can “stack’ several services, deferring high capital-cost network projects as well as serving other functions for the large amounts of time when the network is not loaded at peak capacity.

The greatest challenge to such deployments is that most power system operators do not have an accessible means of valuing upgrade deferrals. Therefore, benefits must be examined and established on a case by case basis. This makes it difficult to achieve economies of scale of demand response solutions. An extensive study by Sandia National Labs found that the benefits associated with avoiding or postponing network upgrades can easily be as large or larger than those of the more direct marketed services reported by other authors [121].

Power quality

Power quality is a generic term which is used to describe unwanted disturbances of electricity supply. It can be defined as the deviation of the voltage and current waveform from the pure sinusoidal wave. Power quality can be characterized by:

- Voltage and current unbalances
- Short- and long-term voltage sag and swell
- Poor power factor
- Voltage and current harmonics
- Flicker

Poor power quality can reduce the life of equipment and grid reliability. This can cause:

- Unexpected power supply failures (breakers tripping, fuses blowing)
- Equipment failure or malfunctioning
- Equipment overheating and leading to their lifetime reduction
- Increase of line losses which results in poor system efficiency
- Damage to sensitive equipment (computers, control systems)
- Electronic communication interferences

These impacts are a financial cost to utilities and customers. It is therefore important to ensure good power quality. In recent years, power quality problems have increased, partially caused DER, such as rooftop solar, household batteries and EVs, which employ power electronic converters for grid connection. This is compounded by the growing use of non-linear loads. Traditionally, utility companies have utilized devices such as voltage regulators, capacitor banks, and transformers to improve power quality. Smart charging of EVs and the V2G are an alternative to this investment. They can improve power quality by effectively controlling voltage and power factor. The following sections describe how the EVs can economically and technically improve power quality.

Adequate voltage control is essential for proper operation of the power system. Generally, power system voltages are regulated within the defined limit by controlling reactive power. Decreasing reactive power causes voltage to fall while increasing it causes voltage to rise.

Voltage control has become more challenging in recent years as increasing amounts of DER export power into networks that are already operating near the top of their voltage ranges. V2G equipped EVs with appropriate controls could offer voltage support and power factor correction by controlling the reactive power without material effect on the battery. Reactive power can be injected into the grid from a V2G EV charger by controlling the AC-DC converter and the DC-link capacitor without affecting the current drawn from the battery. This also means that, in case of DC chargers where the converter is installed in the charger instead of in the vehicle, the vehicle may not be required to be plugged-in for the charger to provide reactive power support. This makes the installation of V2G DC chargers extremely useful for reactive power control.

Many studies have reported the effectiveness of reactive power support from EVs in voltage control and power factor improvement [122-128]. Marra et al. proposed a storage strategy using EVs to reduce the voltage rise as a result of high penetration of roof-top PV units in distribution networks [126]. A 3.7 kW three-phase EV charger with 14.5 kWh battery and a 6 kW three-phase PV unit were deployed for testing the effectiveness of the proposed method. It demonstrated that the proposed EV charging strategy reduced voltage rise by approximately 6.1 V at the point of common coupling (PCC), regulating the voltage within the defined international limit, as shown in Figure 28.

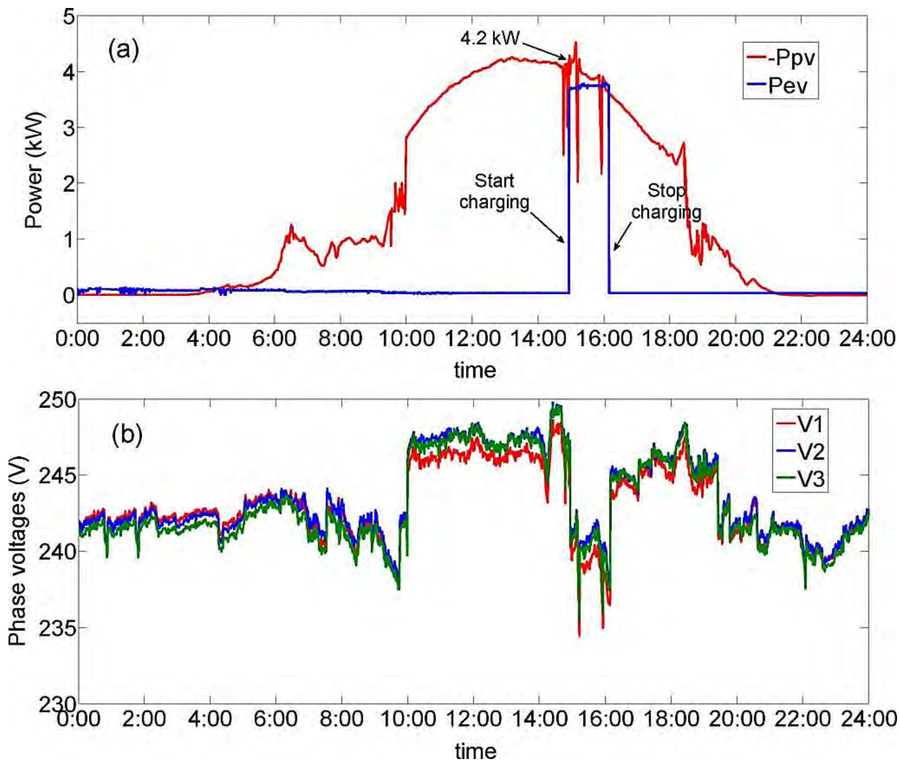


Figure 28: Voltage rise reduction using EV charging [126]. Reproduced with permission from the copyright owner.

The authors of [85] proposed a three-stage algorithm for coordinating the operation of EVs and other equipment in the electricity network to mitigate voltage issues and reduce transmission losses. The method employs day-ahead forecasting of tap changers and capacitors (the first stage), followed by fair distribution of the aggregated and individual EVs in the medium-voltage (MV) and low-voltage (LV) networks (second and third stages). The study demonstrated that the proposed algorithm improved network performance by effectively regulating the voltages and minimising the losses without having a major impact on the EVs charging level.

The authors of [127] proposed an effective method of controlling the charging/discharging rates of EV batteries for mitigating solar impacts and supporting the local voltage. This method took into account influence of sudden travel of EV owners and passing clouds. It was validated using a practical network from Australia with 24 kWh batteries and 4 kW rooftop PV. As shown in Figure 29, the proposed method is an effective way of mitigating voltage rise and fall issues compared to constant rate charging.

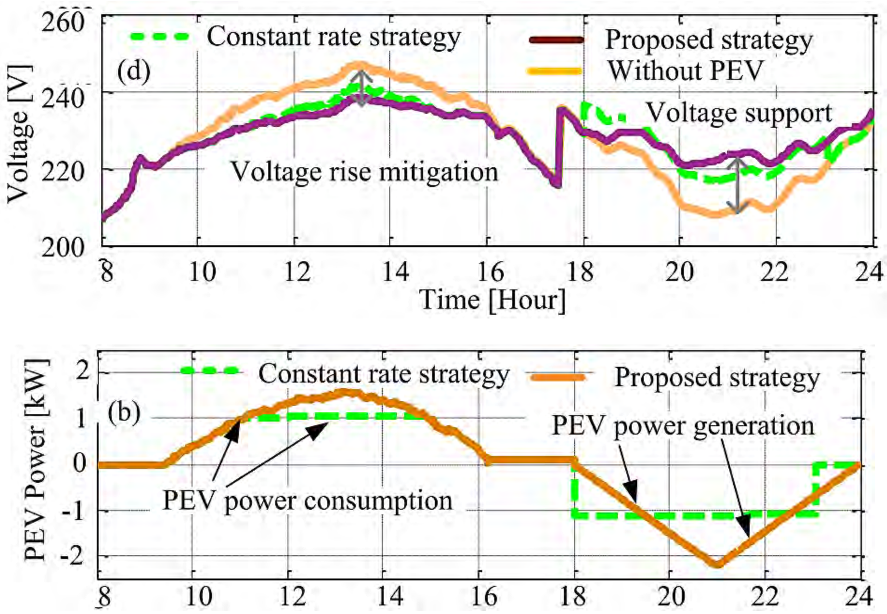


Figure 29: Voltage support from EVs in mitigating both low and high voltage issues [127]. Reproduced with permission from the copyright owner.

System security

System security refers to the ability of the power system to quickly respond and continue operating within defined technical limits following unexpected disturbances, such as loss of generation, load, or transmission faults. The power system is secure when its voltage, frequency, and rate of change of frequency stay within appropriate limits and recover adequately after disturbances.

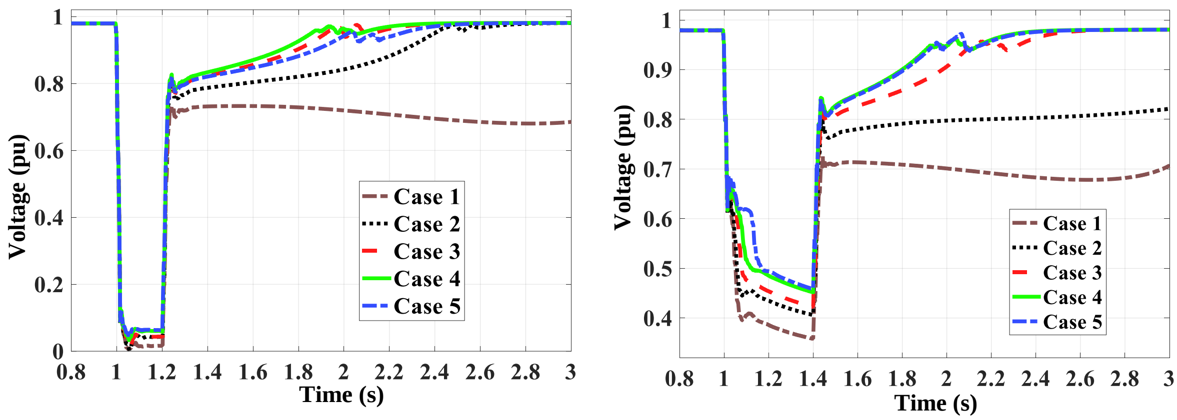
To ensure the security, power systems must ensure sufficient system strength and inertia. Inertia is defined in the Australian National Electricity Rules (NER) as : “*contribution to the capability of the power system to resist changes in frequency by means of an inertial response from a generating unit, network element or other equipment that is electromagnetically coupled with the power system and synchronized to the frequency*” [129]. On the other hand, system strength is defined by the Australian Energy Market Commission (AEMC) as [130]: “*a characteristic of an electrical power system that relates to the integrity of voltage and voltage waveform following a fault on the power system. In other words, it’s the capability of power systems to maintain the correct voltage waveforms. System strength can be measured by the availability of the fault current at a given location. High fault levels are generally found in a strong power system while low fault levels are representative of a weak power system. When* *the system strength is high at a connection point the voltage changes very little for a change in the loading (i.e. a change in load or generation). However, when the system strength is lower the voltage would vary more with the same change in loading"*.

Some synchronous generation units are required online to provide system strength and inertia. This means that there must be sufficient demand to consume the power generated by these synchronous generators. According to the AEMO, the minimum operational demand requirement for South Australia (SA) is around 550 MW with two synchronous condensers installed while operating as an electrical island. This can be reduced to 450 MW when four synchronous condensers are installed in late 2021 [131]. As a result of accelerating uptake of distributed PV, SA has already experienced operational demand as low as 458 MW which is lower than the minimum demand requirement. With the current 200 MW pa growth in PV, the SA power system could reach zero operational demand in the next two to three years [131]. Operating the power system in such a condition is challenging. To resolve these issues, AEMO suggested urgently establishing a back-stop mechanism to curtail distributed PV when extreme and unusual operational circumstances arise. It has been revealed that approximately 200-500 MW of distributed PV power curtailment may be required by spring 2020, which could increase to 1000 MW by spring 2024. EVs, especially with V2G chargers, may provide an alternative means of managing these issues.

Increasing the demand on the power system by shifting EV charging can have significant benefits for managing electricity system security. Especially in South Australia, increasing the load during the day will reduce the distributed PV curtailment. Mechanisms such as SA power networks' "Solar Sponge" tariff is a means of doing this. This tariff offers a low-cost period in the middle of the day aimed at increasing demand to absorb excess solar [69]. Smart chargers that schedule EV charging based on demand, price, and other network constraints can shift the EV charging to high PV production periods and alleviate minimum operational demand constraints.

While managed charging can increase demand, allowing synchronous generation to run, V2G technology with suitable control could offer the inertia support and the fault current contribution itself. This would allow the system to operate securely with less synchronous generation. Current research aims to control power electronic converters to mimic synchronous machine inertia. This type of control slows change in frequency by providing virtual inertia to the system. The authors of [132] developed a virtual synchronous machine control for single-phase EV charger to provide the inertia and damping to the power systems. This control can seamlessly create an islanded grid in case of outages, providing back-up power to local loads. Effectiveness of the proposed inertia emulation control was validated through simulation and experiment.

V2G EV chargers are also capable of fault current contribution and post-fault reactive power support, as demonstrated in [133, 134]. This study employed a new V2G approach of four different control schemes, enabled following a fault. The key objective was to assist post-fault voltage recovery through injecting active and/or reactive power. Case studies were conducted in two IEEE test systems with 25% EV loads. Voltage excursion following a three-phase to ground fault is reprinted in Figure 30, where Case 1 is the base case without V2G support and Cases 2-5 are based on the proposed approaches. As can be seen, the proposed V2G approach is very effective in alleviating voltage instability in the short-term.



(a) (b)

Figure 30: Voltage excursion following a three-phase to ground: (a) nearby fault (b) long-distance fault [133, 134]. Reproduced with permission from the copyright holder.

Data and demand forecasting

Network engineers need to know the load growth patterns to adequately plan the network. This requires data on charging patterns. Charging data is also required to make short-term operational forecasts of EV charging. This data can be anonymised but must be collected with the appropriate agreements [135]. Data on EV use and charging can be used in several domains, such as

- Planning – to determine network adequacy and reinforcement requirements
- Operational – to forecast network demands and schedule demand response.

Many of the early stage EV trials that have been undertaken by networks to date have been about collecting data to understand charge patterns and network loading better. The My Electric Avenue project by EA Technology in the UK was a first step to understanding the impacts of localised EV uptake. This project showed that the After Diversity Maximum Demand (ADMD)[3] needed to be doubled from 1 kW to 2 kW in the presence of large numbers of EVs if there is no control of charging [136]. Tennessee Valley Authority have undertaken a project to source charge pattern data since 2018. This project used a device that plugs into the diagnostic port in customer electric vehicles and transmits charge and location data. Customers receive a $100 reward for participation [137]. Energy Queensland recently started a similar project [138].

Currently, customers may not need to notify the Distributed Network Service Provider when they install an EV charger. However, with the EV uptake, unplanned charging can cause network congestion if the network is not adequately sized. For instance, Western Power Distribution has increased the capacity of the network to cater for EV uptake, and has plans to reinforce parts of the network [139]. This requires visibility of where chargers are installed. To increase this visibility, AEMO requires registration for two relevant groups of customers:

- DER (including V2G EV chargers) as part of its DER registration
- Customers who participate in the energy market as part of its demand side participation register [133, 140].

[3] ADMD refers to the expected maximum demand of a connection point co-incident with the local network peak. This value is used to size local LV networks. A customer's ADMD is usually significantly lower than their anytime maximum demand.

As the V2G capable EV chargers can act as DER, it will be registered in the DER register, whilst customers who participate in managed charging programs in the demand side participation register. Unmanaged single directional chargers will not be registered in either.

System resilience

As the frequency and severity of weather extremes increases as a result of global warming, there is greater need for resilience in the electricity system more generally. This is reflected in a recent summer operations review by the operator of Australia's national electricity market (NEM), which states*: "Australia's physical gas and electricity infrastructure is being increasingly challenged by extreme and high heat and fire periods. The need to harden these assets to more extreme climatic conditions and consider opportunities to enhance the inherent resilience of the NEM when planning and delivering either new projects or replacing existing infrastructure will be a necessary element of future NEM planning"* [83].

Resilience is a broader term than reliability. The resilience of the electricity system is determined by its capability to *"(1) anticipate, (2) absorb, (3) adapt to and (4) rapidly recover from disrupting events"* [141].

V2G EVs can increase resilience in a number of ways:

- Frequency control services (as presented in 3.2.1) can increase the system's resilience to faults
- When V2G chargers can operate in island mode they can increase reliability after faults by backing up customer load (as presented in 3.1.1).

Resilience benefits may be especially useful to utilities for customers who have life support equipment. In some cases a reliable supply can be a life or death proposition for customers who depend on electricity. Networks and retailers have special requirements for customers with life support equipment [142]. Obligations include:

- Outage notification
- Assistance in developing an outage plan
- Maintaining supply to the customer apart from planned or unplanned outages

Failure to meet these requirements may incur penalties for organisations (e.g. [143-145]).

V2X services are a potential means of increasing supply reliability to these customers. This benefits the customers themselves, but also utilities through increased compliance with their requirements and reduced corporate image impacts.

3.3 Societal co-benefits

The chapter began by presenting benefits that accrue to individual users and service providers, and then benefits to the technical operation of electricity systems. This section will detail benefits that are publicly shared. These are generally indirect co-benefits that improve the process and outcomes of transitioning our energy systems.

3.3.1 Equity

Energy equity refers to the availability and affordability of energy, for all [146]. In Australia, inequity is increasing in recent years as energy prices have risen sharply, with households in the lowest income quartile spending a far higher percentage of their income on electricity and gas than other households [147].

Advocates for low income households support measures that reduce the cost of providing energy across the supply chain, including via demand response mechanisms, and also emphasise the importance of reducing greenhouse gas emissions [147]. As detailed in section 3.2, the grid services offered by V2G have the potential to reduce the cost of producing and delivering energy, while increasing the ability of networks to incorporate more renewable energy. V2G can also assist networks to manage the additional load of EV charging, as transport energy increasingly transitions to electrification.

3.3.2 Health and climate

The expected health and climate co-benefits of V2G arise due to displacement of fossil fuels from transport and electricity systems. V2G will help displace fossil fuels from Frequency Control Ancillary Services (FCAS) in the near term and may support greater renewable electricity penetration in the medium term. In Australia, this is expected due to a large proportion of coal-fired generators reaching the end of their technical life [148]. As a result, V2G may not be ultimately responsible for much additional decarbonisation; rather, it may support decarbonisation at a lower cost and more rapidly than other options. V2G may have a greater hand in the electrification of automotive transport and associated additional emission reductions by paving the way for more attractive charging deals and faster uptake of EVs.

Nevertheless, over time this decarbonisation of electricity generation and transport will generate significant public health benefits [7], [38], [149]. In the US alone, climate change and air pollution attributable to electricity generation and transport cost an estimated USD470 billion per year [7]. In Australia, there are an estimated 684 deaths per year as a result of transport emissions, costing USD6.4 billion per year using a local estimate of USD10.4 million of the value of a statistical life (VSL) [150]. Additionally, recent research by the Australian National University suggests up to 36,765 deaths in Australia over the last decade may be attributable to extreme heat [151], equating to a cost of USD328 billion using the same VSL used by [150].

Studies have shown that customers have a strong ethical preference for charging their EVs with renewably sourced energy. One study showed that customers were willing to pay an additional $0.61 per hour for renewable energy at public charging stations [152], while another showed that customers with solar power had an increased preference for charging at home [153]. Likewise, organisations with EV fleets may wish to strengthen their claims to sustainability by maximising renewable energy used in charging.

However, it is important to note here that V2G technology, and EVs more broadly, may also represent a public health challenge to the extent that they could perpetuate ‘conventional [private] automobility’ [7], [154]. Congestion caused by private vehicle ownership—irrespective of fuel source—can reduce access to services, employment and social support [7]. Likewise, EVs and V2G will not, of themselves, reduce road accidents, which are a leading cause of death and injury, or physical inactivity, which leads to obesity, diabetes and heart disease [155]. Other interventions, including active travel, public transport, and ‘last mile’ options will be needed to address these challenges and extend ‘the human range of mobility’ [156].

3.3.3 Trust

Driven by high prices, complexity, inequity, and a perceived lack of leadership and transparency, many Australians have become increasingly disengaged from the energy market [157]. However, Australians are highly engaged on energy’s potential to support outcomes like comfort, self-sufficiency, a sense of community and environmental sustainability

[157]. V2G, like other decentralised clean energy technologies, may present an opportunity to empower energy users, improve energy equity and ultimately help address the sector's trust deficit, which remains very low despite recent improvements, and is an issue for the entire sector [158].

However, for these new technologies to realise these benefits, recent experience suggests it will be important to move past dated conceptions of people as passive consumers or barriers to technology adoption; to co-design support schemes with people to reflect their aspirations for the future; and to implement them with transparency and fairness [159], [160].

Case study: Trust and customer acceptance of managed EV charging

Retailers operate in a competitive market. This means that attracting and retaining customers is important. EVs can increase customer satisfaction and energy literacy. The Electric Nation project undertaken by Western Power Distribution measured how acceptable customers found charging arrangements before and after managing their charging remotely. Utilities may expect that remote charging management will be seen as an impost by customers. The "Electric Nation" project found that contrary to this customer satisfaction with charging arrangements did not decline with management, and in some cases increased slightly. Before managed charging 78% of participants rated satisfaction 8/10 or higher, while after managed charging this increased very slightly to 79%. Note the relatively small sample size of the "after" group means the error bounds on the post-trial survey are larger [108]. Austin Energy used customer segmentation to target participants in their "EV360" pilot. This segmentation was used to send personalised marketing materials to prospective participants. An example of the postcard used by Austin Energy is shown in Figure 31. Austin Energy found participants were highly satisfied with the EV360 time of use rate, with 83% of customers rating it 8/10 or higher [113].

Figure 31 Austin Energy "EV360" postcard [113]. Reproduced with permission from the copyright owner.

4 Challenges

The path to delivering the full benefit stack contains several regulatory, commercial, technical, and social obstacles. These may:

- Make realising benefits more challenging,
- Act as counterpoints to benefits and act to reduce uptake,
- Relate to the environment in which V2G operates.

The net effect of these obstacles is to reduce the amount of value that can be realised and hence reduce the uptake of V2G.

While there are many benefits, V2G impacts energy and transport in many ways and if it is inappropriately managed it may increase the very energy problems it intends to solve. Similarly, V2G services may impact car's usage for transportation. These risks reduce uptake and usage of V2G services. It is always possible for customers to opt out of providing V2G services.

A free flow of benefits and uptake of V2G services depends on an environment that allows it. Historical distrust of utilities makes presenting a convincing case for V2G more challenging. And more broadly uptake of V2G requires cooperation between organisations that may not have previously worked together. These issues can prevent business models which may otherwise enhance the value of V2G.

Resolving these challenges will take coordinated action from several different stakeholders.

A summary of the challenges presented in this chapter is in Table 9.

Table 9 V2G EV barriers

Challenge	Who it applies to	Reference
Awareness of V2G: EV owners are currently unaware of V2G	EV owners	4.1.1
Reduced flexibility & convenience: V2G can reduce a vehicle's availability for its primary transport service	EV owners	4.1.1
Symbolic meaning of mobility: People assign a variety of meanings to vehicles, such as "freedom". V2G can conflict with these meanings	EV owners	4.1.1
Vehicle health: V2G may cause battery degradation (or be perceived to)	EV owners	4.1.1
Cost: V2G is currently expensive and few products can provide it	EV owners Energy market	4.1.1
Privacy: Cybersecurity, data privacy, and control over personal data are important to EV owners	EV owners	4.1.1
Wider process of socio-technical change: Energy system participants (both end use customers and market participants) may be risk-averse which can slow adoption of V2G	EV owners Energy Market	4.3
Charger and battery efficiency: Chargers and EV batteries will always have some energy losses.	EV owners Energy market	4.1.1
Customer buy in: Aggregators require customers to want to provide services from their EVs.	Aggregators	4.1.2

Challenge	Who it applies to	Reference
Accessing multiple value streams: Aggregators must be able to see and access multiple value streams. This includes visibility (knowing it exists) and entry requirements (capacity threholds).	Aggregators	4.1.2
Co-incidence: V2G chargers all operating synchronously can cause congestion in the network and volatile prices in the market	TSO/DSOs Energy market	4.2.1, 4.2.2
Vehicle availability for services: EVs are not plugged in all the time. If they are not plugged in when required they cannot provide service	Aggregators	4.2.1
Response speed and accuracy: While EVs are batteries, there are more elements to the control and a restricted amount of energy they can provide	Aggregators	4.2.1
Network congestion: V2G can cause localised overload in the network	TNO/DNSPs	4.2.2
Power quality: V2G can cause a reduction in power quality (e.g. voltage compliance, harmonics)	TNO/DNSPs	4.2.2

4.1 Barriers to uptake

This section considers the barriers that prevent uptake of V2G for the users of these vehicles and services. These barriers span people, process, organisation, and technology.

4.1.1 For users

Our review has identified four key barriers that may impede the adoption of V2G among users: (1) low awareness; (2) reduced flexibility and convenience, (3) the symbolic meanings that people ascribe to mobility, and (4) the costs and implications of using the technology. As with V2G's benefits, its impacts will also be felt by different groups, in different ways, at different times, to different degrees.

Awareness

According to a recent study, 'a sense of unfamiliarity and ambivalence permeated the focus group discussion' [7] when questioned about V2G. This is a problem, because, as argued in the Parker project final report, 'a proper introduction to V2G' is required to build acceptance' [161]. Additionally, there is a need for basic energy literacy among users to support V2G adoption and business models (to say nothing of consumer protection and wider energy democracy concerns), as 'It is their EV, their battery, and their power that is being used, sold, stored, and served' [7].

Accordingly, there is a clear need for wider awareness of the V2G concept and its value. This may be the most immediate social barrier to wider V2G adoption. And interestingly, this low awareness of V2G itself may also represent an opportunity. A recent German study found that, while people had low levels of awareness of V2G technology, this meant they also lacked preconceptions against it [162]. It is therefore possible that 'if not too troublesome… most are generally willing to participate with limited reservations' [7]. And, as the Parker project found, consistent with theories like diffusion of innovation and social construction of technology, early adopters can act as ambassadors for V2G among others as they become increasingly familiar with and confident in the technology [161].

Case study: attitudes to EVs and V2G (Nordics)

Researchers investigated the willingness to pay (WTP) for EVs and V2G capability among more than 4000 people in Denmark, Finland, Iceland, Norway, and Sweden [21]. Purchase price, recharging time, range, renewable electricity fuel source, and V2G capability were all important factors. Young people under 30 and families with children were more prepared to pay for EVs, as were people with no car compared with those who already had one or more. There was less support among car users who drive longer distances. Importantly, prior experience with EVs was very strongly correlated with support for EVs and, less strongly, for V2G. Preferences for range varied noticeably between countries: it was seen as twice as important in Norway and Iceland than in Finland, perhaps due to greater familiarity with EVs, their current limitations, and their potential for technical improvements. WTP for V2G was only significant in two counties, Norway and Finland, and 'when divorced from onerous contracts'. The authors suggest this could be due to greater experience with EVs in Norway, and with national energy security considerations in Finland. People in the three other countries were not willing to pay more for a V2G-capable EV, and were more sceptical of its potential revenue and concerned about potential battery degradation. However, only 10 per cent of respondents had heard of V2G, so these findings are perhaps unsurprising.

Implication: more work is needed to communicate the financial and non-financial value of V2G, and to educate people about V2G in general. People may also be reacting to perceived costs of V2G, specifically the 'burdens of planning trips in a poorly designed system' (p.532), in which case governments and industry should work to reduce associated (real and perceived) 'work'.

Flexibility & convenience

There is good evidence on people's expectations for EV range and recharging time (see for e.g. [17], [163], [164]). These two factors in particular impact on people's time of use of charging, and ultimately their perceptions of flexibility and convenience [17], [21]. V2G's impact on these issues is less well understood, but, depending on V2G scheme design, may place additional impost in terms of (in)flexibility and (in)convenience. If so, potential mobility would come at the cost of additional V2G revenue [162]. People have also been found to hold concerns with V2G's potential to cause inconvenience, an empty battery, a loss of freedom—with some stating they would refuse to participate in V2G at all [21]. Of particular note is that 'drivers see high inconvenience costs with signing V2G-EV contracts' [38p. 323], even when easy to fulfil [7].

This strong aversion to inconvenience, and preference for flexibility, was also seen in the Parker V2G demonstration project in Denmark:

> No EV owner or fleet manager will be motivated to sign up for V2G if it means their vehicle will be unviable at unexpected periods … The overall V2G setup must guarantee enough flexibility in its operations, as customers' needs are above all other requirements [161p. 12].

Fortunately, it may be that contracts are the concern, rather than V2G participation itself [21]. More awareness of V2G and its benefits would be of assistance in this regard. Additionally, aggregators should consider flexible remuneration schemes, intuitive user interfaces, and machine learning or other approaches that can maximise battery availability for when it is needed. This might reduce people's concerns about V2G's costs [108], [21], [7].

Case study: free V2G for freedom? (Germany)

A survey of 611 people in Germany, including 14 EV users, explored willingness to pay for V2G, and preferences for various aspects of V2G scheme design [162]. The study found that prior awareness of V2G was a critical determinant of people's willingness to participate in a V2G scheme, hypothesising that prior awareness indicates greater knowledge and less fear about the technology. V2G's potential to support renewable electricity integration was valued highly. The largest concerns with V2G were its potential implications for battery degradation and for people's flexibility. Another strong concern related to cyber security, especially the risk of uncontrolled access by third-parties to people's vehicles. As noted in other studies, people applied high discount rates to V2G revenue, some as high as 20 per cent. Accordingly, one-off payments were strongly preferred. Importantly, the study suggests that some frequent car users may have specific characteristics that could make V2G impractical for them, irrespective of the level of remuneration paid. On the other hand, remuneration may not even be required for many users if scheme design supports people's desire for freedom.

Implications: V2G aggregators should tailor V2G schemes to individual users. Meaningful engagement/co-design work will be required to ensure people's needs and aspirations are well understood and reflected in scheme design.

Case study: contracts and V2G (USA)

Researchers investigated willingness to pay for V2G among more than 3000 people across the US [38]. People indicated a very strong preference for earn-as-you-go or up-front remuneration over contractual terms with fixed requirements for V2G participation. People applied a heavy discount of 53.5% to projected revenue—this is high even by standards for energy efficiency (e.g. [165]). According to the authors, 'drivers see high inconvenience costs with signing V2G-EV contracts', likely due to desire for flexibility and lack of awareness about the relatively small amount of required vehicle down time. People are likely to require considerably higher remuneration for V2G if on fixed contractual terms—which could undermine V2G's value.

Implications: Aggregators should focus on flexible remuneration schemes such as earn-as-you-go or up-front payment over fixed contractual terms.

Symbolic meaning

There is ample evidence on the rich symbolic meanings, or scripts, that people attach to cars and mobility (see for e.g. [166],[16]). Examples of these include status or prestige expressed by a particular car, the importance of a car's brand over its functional qualities, or feelings of freedom and independence [167]. V2G may represent a threat to symbolic interpretations among some, particularly if/when the technology is perceived to conflict with traditional meanings of the car such as freedom [58]. Further, many people have legitimate concerns about the environmental and social impact of lithium-ion batteries, and whether these offset the other environmental benefits of EVs—although these concerns can sometimes also be understood as political [17],[58],[38]. Finally, aesthetical considerations have been a significant issue for EVs, and have a strong link with symbolism and emotions [17],[15]. While V2G itself may lack significant aesthetical impacts (positive or negative), its home charging infrastructure may.

The symbolic meanings of mobility could also represent an opportunity to promote V2G. One study has found that people may be happy to participate in V2G *even without revenue* if the design of the scheme did not impair their sense of freedom [162]. And, while, V2G itself currently lacks a script, there is an opportunity for users, ideally with encouragement from OEMs, to build new scripts through 'tinkering', or reinvention, that could support faster diffusion [7]. One example of the importance of scripts is the aftermath of the Fukushima disaster, which saw a significant increase in V2G, V2H and energy storage more broadly [168],[40], perhaps due to scripts of self-reliance or reliability.

Case study: range anxiety as reaction (Nordics)

Some researchers argue that technical and psychological concerns are insufficient to explain people's ongoing concerns with EV range [58]. Range anxiety, they argue, persists among some even in the face of battery improvements, charging station deployment, and increased awareness of and experience with EVs. Drawing on expert interviews and user focus groups in five Nordic countries, and Hirschman's concept of reactionary rhetoric [169], the authors argue range anxiety can also be seen as a rhetorical tool. In this conception, EV range is argued by some to represent *jeopardy*, or danger, and used to rationalise EV rejection and 'avoid changing their behaviour or desires'. This may be driven by conflicting symbolic meanings: for example, EV's could be 'limiting their perceived freedom…and thus conflicting with the symbolic nature of a car'. Rhetorical range anxiety could also be used to further wider political goals, such as slowing EV diffusion. The study observes that Norway, with the highest EV penetration in the region, has not really targeted range with its EV support policies, instead focusing on 'valid', and less rhetorical, socio-technical concerns such as EV price. Visible, and rhetorical, policies like free tolls and parking for EVs may also have helped convince wary users.

Implications: focus EV and V2G support on non-range-related issues like cost. Given V2G currently has a blank symbolic slate, further research would be beneficial on how new V2G scripts might be used rhetorically to promote or slow diffusion.

Control

An inherent feature of smart charging, be it V1G or V2G, is the ceding of control from the EV owner to the orchestration engine (typically the aggregator). Range anxiety and minimum range are important determinants in EV owners' willingness to participate in V2G [162], and likewise aggregators need to maximise battery availability to provide grid services. Therefore, this is likely to be a key issue.

Enel-X in the US manage this issue within their JuicePlan by consulting with the customer regarding their needs and providing the means to set a charging schedule (such as daily expected departure time), then obliging customers to be plugged in and connected to WiFi for a minimum proportion of demand response events [170]. Octopus, as part of their Powerloop product, also provide an app for customers to enter their schedule and pay 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% [171].

The override option is particularly important as it gives EV owners the feeling of full control should they need it, regardless of whether they use 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 using the charger's boost button [172].

Cost, efficiency, and cyber security

There are several interlinking concerns that may discourage people and organisations from adopting V2G. Firstly, concerns over V2G's implications for battery degradation are noted in a number of studies as a possible driver of low willingness to pay (WTP) for V2G [162],[21]. This is a nuanced issue, as while using a battery will degrade it faster than not using it, there are multiple variables that reduce battery life and V2G and other forms of smart charging can reduce degradation through better battery management. Detailed discussion of battery degradation is provided in Appendix A.

Second, the current high prices of V2G-capable EVs and chargers (as detailed further in Appendix A) may be a barrier, although these can be expected to reduce over time as production ramps up, as has been the case for batteries and (non-V2G) EVs [17],[7].

Thirdly, the round-trip efficiency and consequent energy losses inherent in all energy technologies is a barrier. Within a V2G system, power loss occurs across meters, breakers and transformers on the grid side, and the power electronic converter, battery and vehicle smart link on the user side. This inefficiency appears as a financial loss V2G users. Who pays for this loss depends on the financial arrangement in the V2G product. For example, if payment is for delivery of service, customers pay for losses because they must put more energy into the vehicle than they get paid for. Appendix A.2.3 has a more detailed discussion of the underlying technical efficiency issues.

Finally, peoples' concerns about cybersecurity, data privacy, and third-party control are cited in a number of studies [173],[162],[7],[21] and will need to be transparently addressed. Cyber security issues may present in several ways:

- Customer's personal information may be compromised,
- Vehicles may be damaged,
- Service providers may lose control of V2G assets, or
- Coordinated and unwanted actions of DER may challenge system security.

Connection and standards

Traditionally networks have managed distribution network constraints introduced by DER using static limits on the amount of embedded generation that can be connected at each point, such as 5kW per phase in evoenergy's network [174]. V2G can increase the amount of DER at a connection point significantly. The Wallbox Quasar alone offers 7.4kW of capacity through a single phase connection [175]. Coupled with a stationary battery or a PV system this can result in significant constraint to the V2G charger's operation. New control methods such as dynamic connection agreements may partially resolve these constraints [176].

Currently only the CHAdeMO vehicle connector standard offers V2G (as discussed in 5.1). There are relatively few vehicles that use this standard in Australia and of these, only the Nissan Leaf allows V2G within the warranty of the vehicle.

4.1.2 For service providers

The previous section discussed barriers for users, which service providers will need to consider when formulating their V2G offerings, and we discuss business models later in section 5.3. Here, we identify the key barriers for aggregation service providers as high start-up costs and the ability to access sufficient potential value streams so that the proposition is viable. In other words, so that “the juice is worth the squeeze”.

As discussed in Chapter 3, there are many possible benefits to V2G. These benefits accrue to different participants in the value chain. Realising all of these benefits requires an organisation to act as an intermediary, or aggregator. Aggregators facilitate the provision of grid services to the market by combining many small resources into a larger, tradeable volumes. Conversely they also combine multiple value streams into single cohesive offerings for customers. In doing so, they manage uncertainty and risk, and encourage competition and innovation [177].

Aggregator businesses providing V2G could emerge from an established entity within electricity or transport, or alternatively, they could be a dedicated start-up business. This is discussed in more detail in chapter 5. Aggregators can face high start-up costs, such as registration with market bodies, systems, and hardware development. They also must procure enough resource to meet minimum market participation levels or provide a service to DSOs. These factors challenge their ability to provide a return to their customers.

In particular, most markets, Australia included, require a threshold of capacity to participate in the market, such as 1MW (around 150 V2G EVs). This can be a large barrier for new entrants who cannot receive any value until they meet this threshold. This is compounded by the impacts of vehicle availability and other issues. For residential batteries actual response may be as low as 50% of the installed capacity [178]. This further increases the capacity required for participation.

Depending on their position in the market, aggregators may not have visibility of value streams or how to access them. Furthermore, Aggregation businesses may lack the technical or financial resources to manage non-delivery and other risks. Initiatives that make grid service needs and their potential value more transparent may encourage new entrants.

4.2 Electricity system

EVs and V2G will have an impact on the energy system. Chapter 3.2 has described how V2G EVs can be used to enhance the energy system. But if not managed correctly, V2G can impact the network in much the same ways as it can improve it.

This chapter describes the electricity system impacts of V2G and how they might manifest.

4.2.1 Electricity production

As discussed in Section 3.2.1,3, EVs can deliver valuable services that assist in electricity production. They may also cause negative impacts on electricity production if several factors are not managed correctly. In this section we discuss these impacts.

Co-incidence

Many of the issues related to V2G are due to co-incidence of energy consumption or generation. The grid is built on the assumption that there is natural variability in load and generation, however response to generation or frequency signals is not location dependant and encourages coincident response. This impact can be seen in aggregated EV response from several trials. A good example of this is from Austin Energy who implemented control through a time of use price signal in their “EV360” time of use pricing product. The aggregated response from participants in that trial is shown in Figure 32. A clear demand peak can be seen when low-cost pricing begins at 7 PM. In the short term (while EVs make up only a small percentage of load) this may be desirable, but in the long term this can cause various grid issues, as described below.

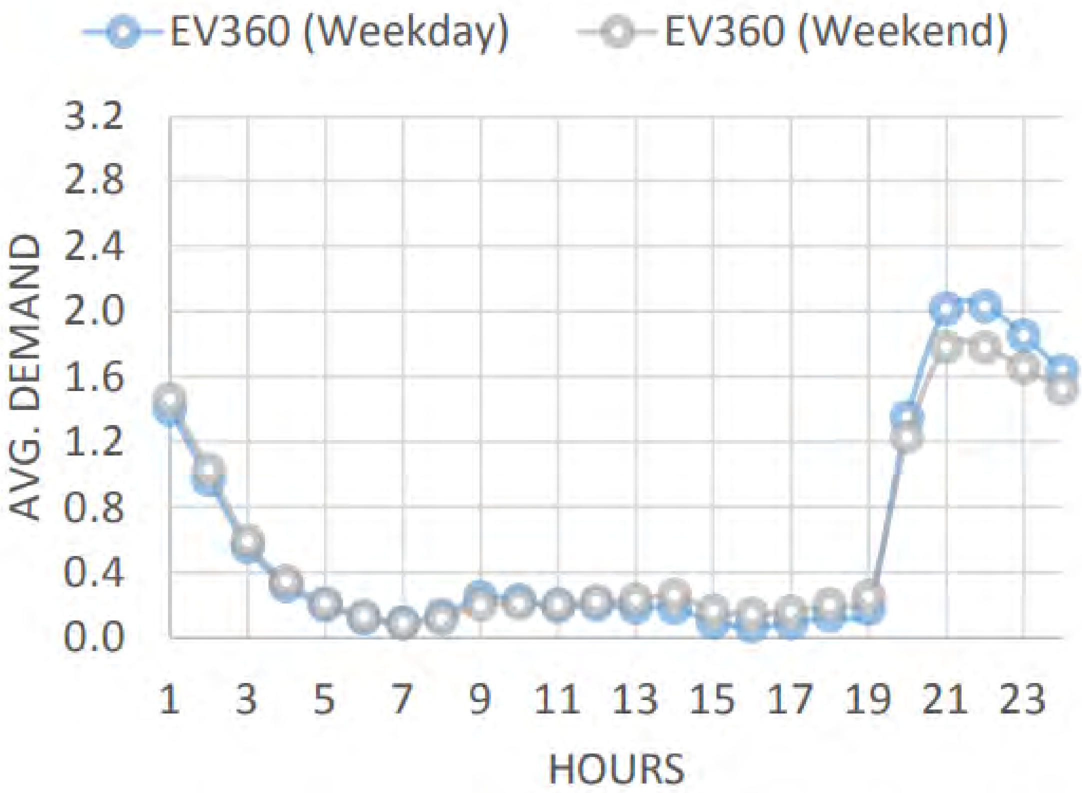


Figure 32: Customer charge response to "EV360" tariff [113]

Sudden increases in load as may be introduced by fixed pricing signals can cause additional fast-start generation to be dispatched to meet demand. An example of this is in South Australia where large numbers of hot water cylinders had timers set at 11:30PM. Operation of all timers simultaneously caused up to 250 MW of load increase within 5 minutes. This spike caused market price to increase as additional fast ramping generation was required to meet demand. The impact on average demand and price is shown in Figure 33. South Australian Power Networks have taken steps to introduce a degree of randomisation into the timing new hot water systems [179].

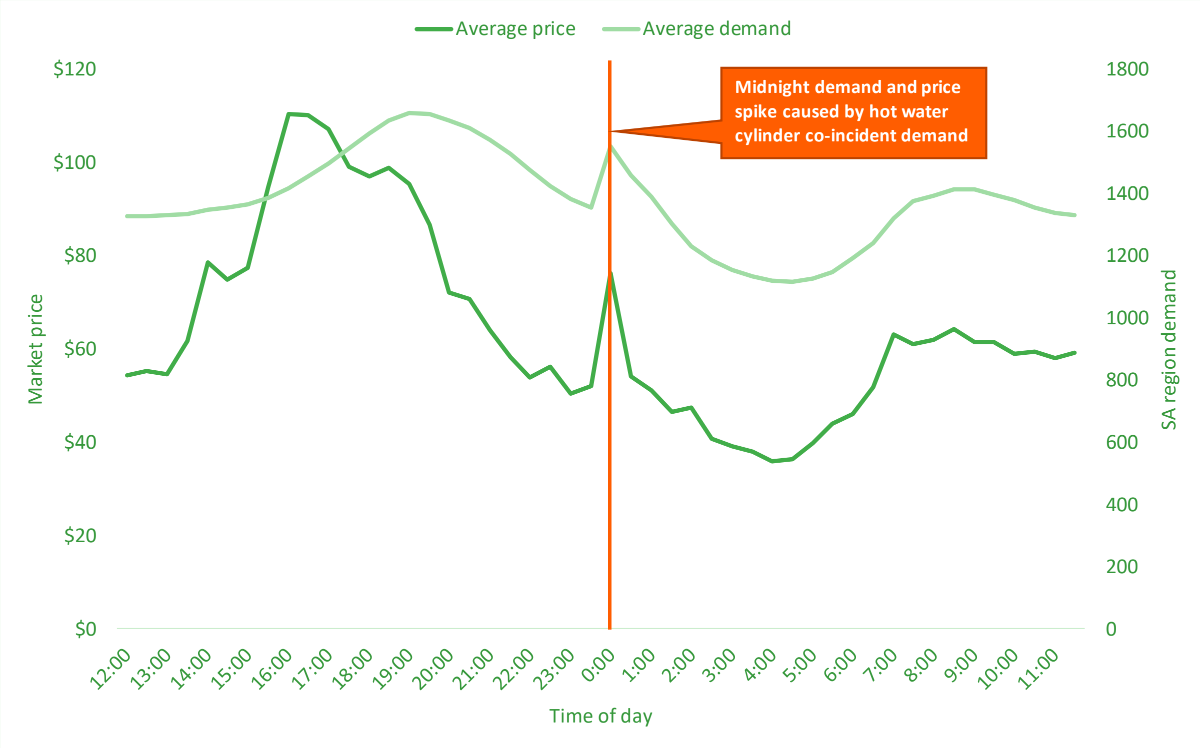


Figure 33: Hot water co-incident switching in South Australia

Many new entrant renewable generators such as solar and wind have highly coincident outputs. This can have a marked effect on energy prices [180, 181]. Figure 34 shows the progression of midday spring electricity market price with solar uptake in Queensland, Australia since 2009. Figure 35 shows the Queensland energy price variability over a day comparing 2010 and 2019. The impact of solar PV can clearly be seen around midday. While the causes for the difference are complex, coincident solar generation has contributed to the impact. EV chargers are likely to have a more controlled output than solar generation however correlation can be introduced through other means, such as tariff (as evidenced by Austin Energy), control (as evidenced by South Australia's hot water control) or a lack of diversity in response characteristics (described below).

Figure 34: Yearly solar output vs price for Queensland

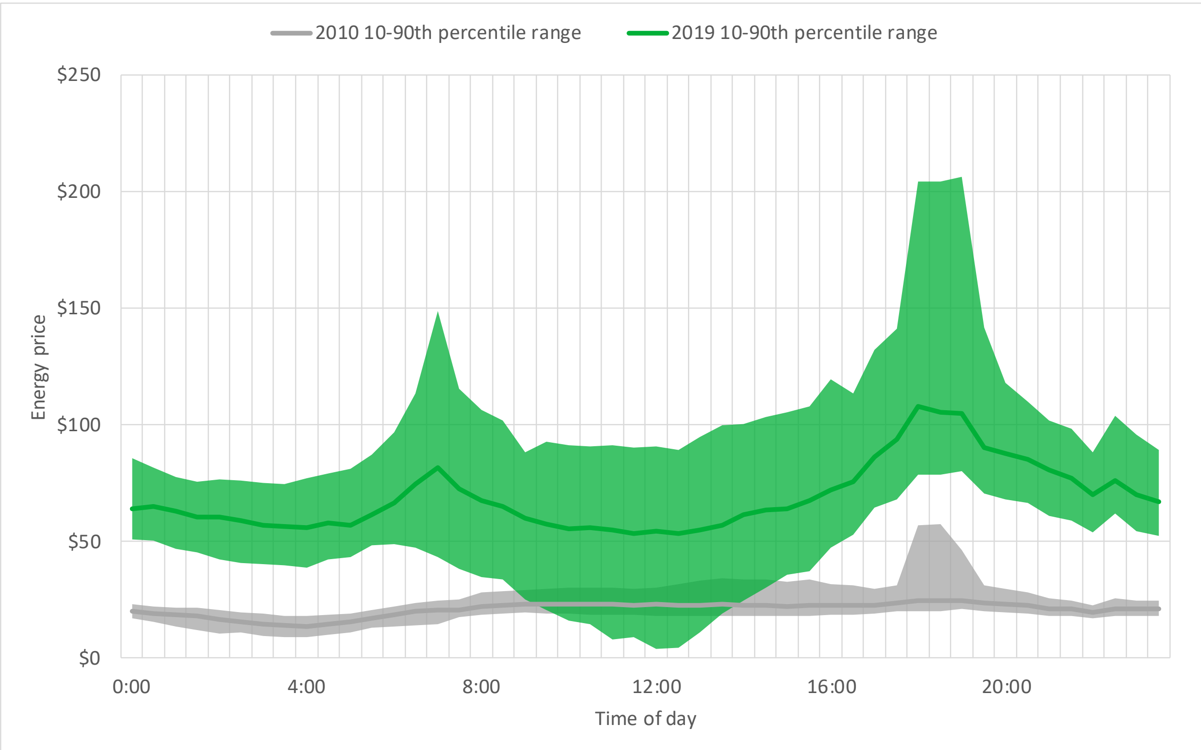


Figure 35: Duck curve - change in average daily energy price 2010-2019 (QLD)

Co-incidence can have an impact on frequency control too. These issues can arise when many small DER such as EV chargers with common frequency setpoints reach a point where they have a material impact on the grid. This may occur when control systems are defined assuming that resources will only have a small impact on the grid. An example of this is was in Germany. PV systems initially were required to disconnect when system frequency exceeds 50.2Hz. While the amount of PV on the grid is small this assists frequency recovery for events involving loss of load. By 2013, 31 GW of solar had been connected, with over 70% of it connected to the distribution network. This had the potential to cause up to 14 GW of generation to disconnect simultaneously. The cost of retrofitting[4] PV systems to mitigate this issue was estimated to be €175m ($289m AUD) [182]. While other studies indicated that the angle distribution due to the impedance of the distribution network may be sufficient to mitigate this issue [183]. In 2012 Germany undertook a program to retrofit existing inverters greater than 30 kW power output at a cost of €300-€500 ($495-$824) each [184].

While many of these coincidence issues will not become important until the numbers of electric vehicles increase, they warrant considering early. Once EV chargers and pricing structures are implemented, it may become difficult or costly to mitigate coincident effects, not only due to the need to alter devices to enable demand response capabilities, but also because it would likely to also require customer consent. As discussed earlier in section 4.1.1, customers may be reluctant to cede control to the utility.

Market price variability and EV availability

V2G chargers can get market price arbitrage revenue because energy cost varies with time. The amount of revenue available depends on the amount of variance. In recent years, the variability of prices has increased substantially as generation from zero marginal cost wind and solar farms has increased while generation from dispatchable fossil fuelled generators has decreased. Figure 36 shows how variability in energy price has increased since 2009 in Queensland, Australia.

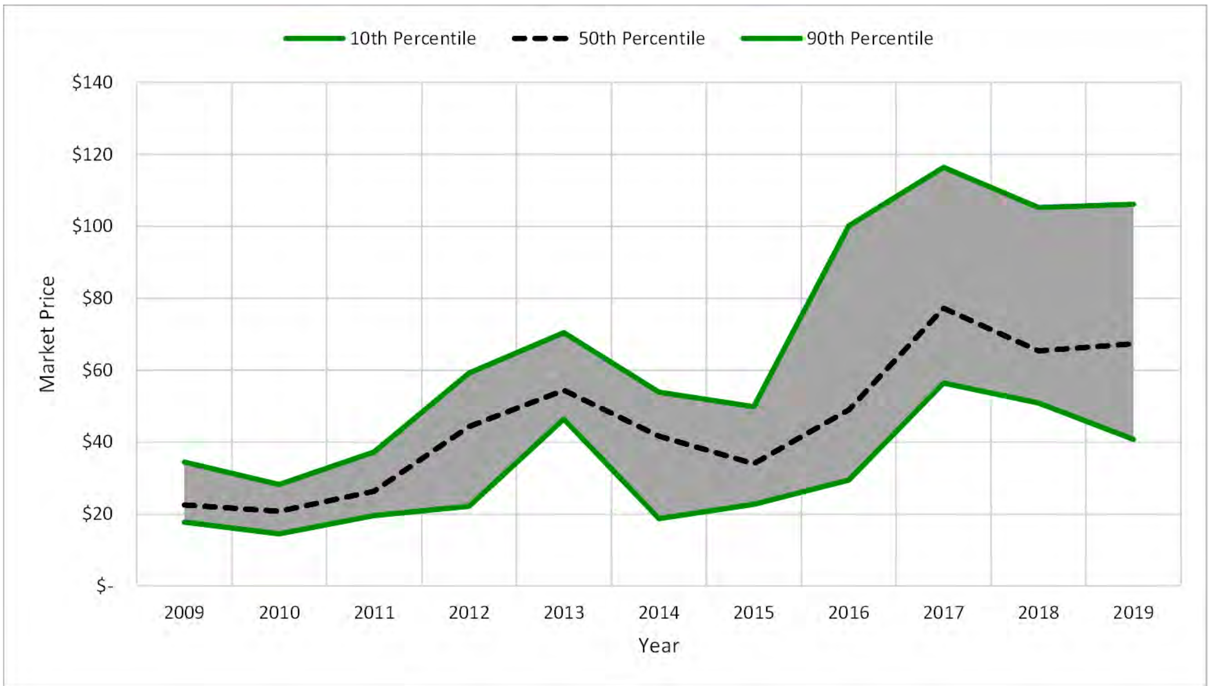


Figure 36: 10-90th percentile energy price range 2009-2019 (QLD)

While currently there is significant variability in energy price in Australia, an increase in flexible capacity will reduce this. From a market perspective this is not an undesirable outcome – high

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[4] In this case, retrofitting involved implementing droop frequency controllers.

price variance indicates the lack of flexible generation and is expected to elicit a response from participants who see the need. This may however challenge business models build on highly variable prices – particularly the few high price events each year. For example, the Hornsdale Power Reserve in South Australia reduced FCAS regulation costs by SA generators by 91%, even though it normally only bids 30MW of its 100MW capacity into the market [185]. There is more discussion on market value streams in Appendix E.

Response speed and duration

While the literature contains many studies on the different aspects of V2G technology, very few have focused on the duration and quality of service. Services such as frequency regulation or load shaving requires significant amounts of energy. Similarly, for frequency regulation – particularly contingency services – vehicles must respond quickly. Batteries are a fast but exhaustible resource, and thus some services, such as contingency frequency regulation, may be more suitable than others.

Figure 37 shows the performance of the EVs under Parker project which demonstrated both normal and contingency frequency regulation [96, 97]. While the EVs provided the requested power, there were significant, delays and inaccuracies. It took 3 s to ramp the EV's power output. Similarly, power output had an 8.7% and 5.2% error for charging and discharging respectively. This could be caused by delays in converter response, communication delays, physical and technical constraints of the equipment, or measurement errors. Additionally, the duration of response proved challenging for the participating EVs, in particular because EVs must have sufficient charge to meet their primary transport purpose.

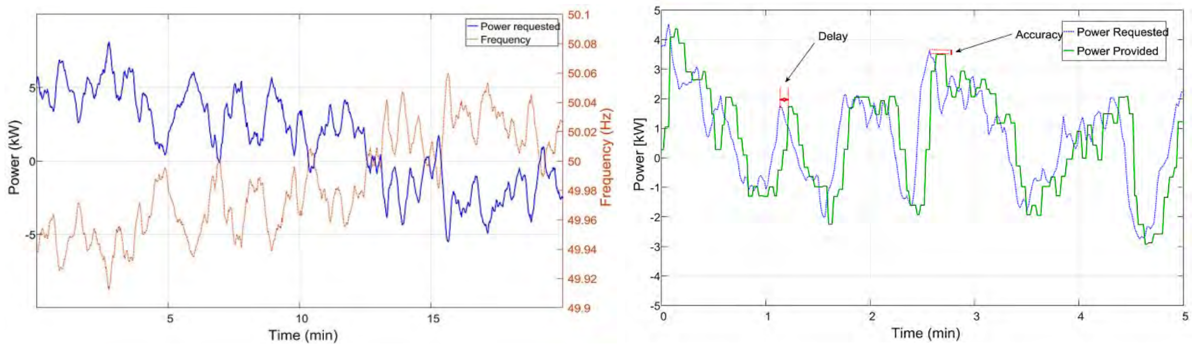
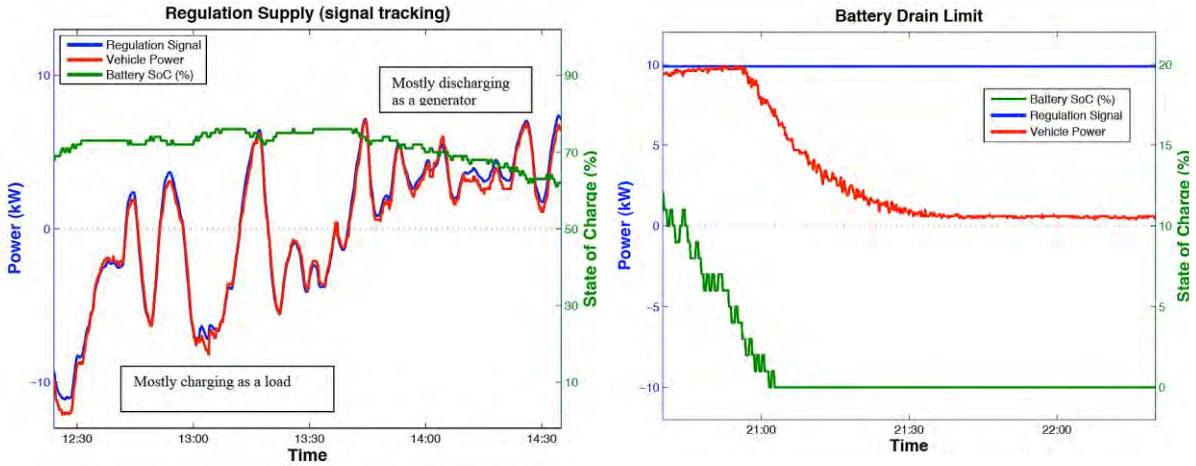


Figure 37: Requested and provided power in Parker project [97]. Reproduced with permission from the copyright holder.

As a counterpoint, A 29-vehicle V2G project at the Los Angeles Air Force base demonstrated up and down frequency regulation and spinning reserve services in the Californian wholesale electricity market [100]. The project showed that EVs could meet the accuracy requirements, with 0.66-0.91pu accuracy for up services and .54-.90pu for down regulation compared to the 0.25 required. [100].

Another V2G demonstration project led by the University of Delaware showed EVs can closely follow requested power signals and respond better than conventional rotating generation as shown in Figure 38(a) [94]. This project didn't detail specific response time. Figure 38(b) shows the length of response required. Excessive regulation up demand could drain the EV's battery. This can leave customers without sufficient charge to drive their vehicles, as well as accelerate battery degradation and interrupt service delivery.



(a) (b)

Figure 38: Frequency regulation services (a) up and down regulation (b) up regulation [94]. Reproduced with permission from the copyright holder.

4.2.2 Electricity delivery

As discussed in Section 3.2.2, EVs can provide many useful grid services, especially if they are V2G capable. However, the unplanned connection of EVs could also adversely influence the performance of the power system, particularly in the distribution network. In this section we discuss how the massive deployment of EVs can affect the electricity delivery system.

Impacts on distribution networks

It is expected that EVs will increase electricity consumption significantly, which may overload networks [186, 187]. Similarly, this extra demand may create large voltage deviations and increase network losses. EV chargers can also increase voltage unbalance and create voltage and current harmonics. [188]. The potential impacts of EV loads on the power systems are illustrated in Figure 39 [189].

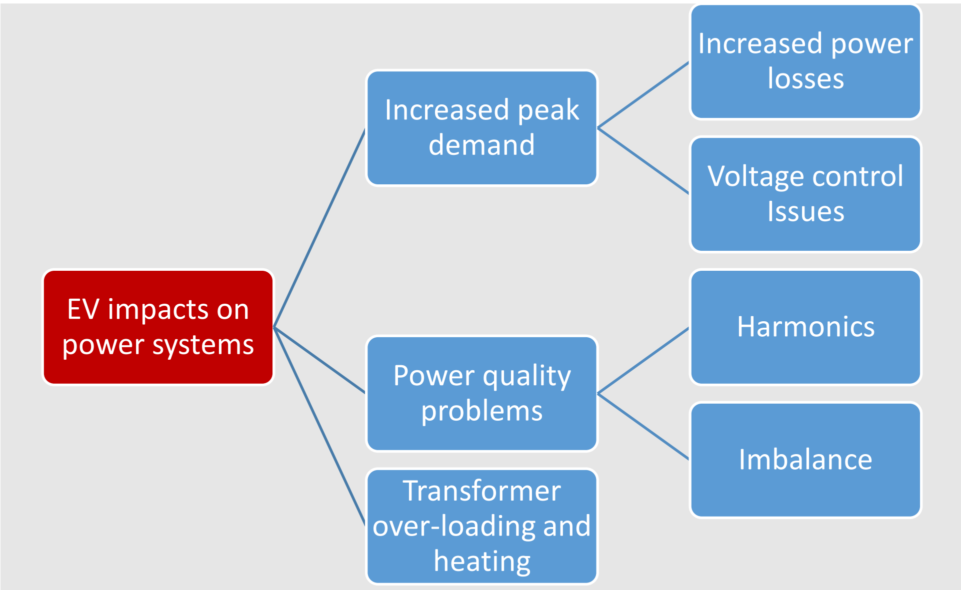


Figure 39: Probable EV charging impacts on power systems [189].

Ultimately peak demand is the single biggest driver of EV integration issues. Without incentives to do otherwise, most people will plug-in their EVs after returning home from work in the evening. This will increase in evening peak load. The “My Electric Avenue” project in the UK showed that unmanaged EV charging has the potential to double localised peak demand [104]. The study presented in [190] showed that if domestic charging is uncontrolled (mostly in the evening), 10% penetration of EVs can cause a 17.9% peak demand increase. 20% EV penetration would increase the peak load by 35.8%. Another study presented in [191] showed that if 30% of total load were EVs, uncoordinated charging would increase peak demand by around 53%.

Peak demand is a key driver of network investment [192]. When demand exceeds the network’s capacity it has several impacts, including:

- overloading network elements, and
- causing voltage sags or swells.

The Electric Power Research Institute, California examined the impact of EV charging on voltage in the distribution network [188]. This research used a low voltage network consisting of 74 houses from a suburb of south Dublin, Ireland. During the test, it was assumed that 50% of the houses in the network had EVs which started charging at the beginning of the test. Figure 40 shows how the uncoordinated charging of the EVs caused the feeder voltage profile to violate standards. Without EVs however the voltage was compliant.

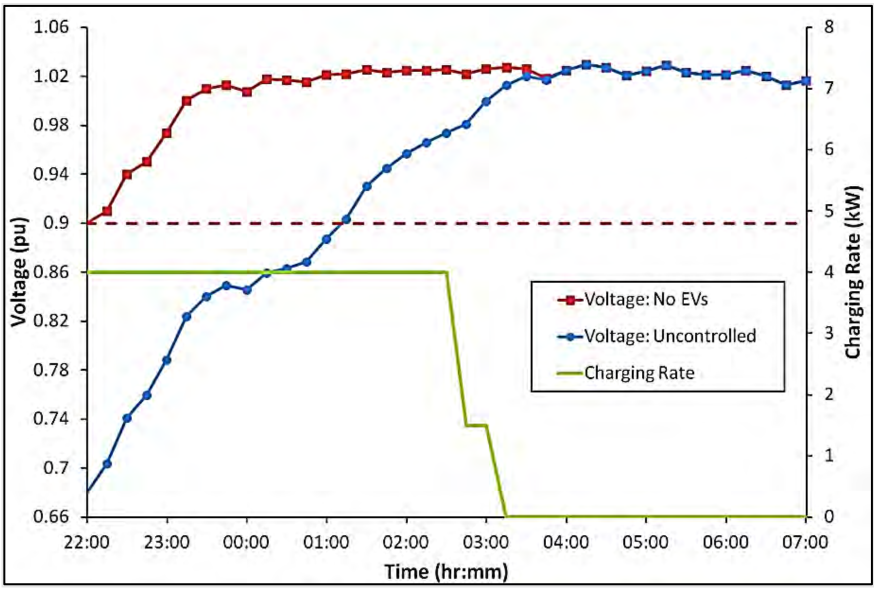
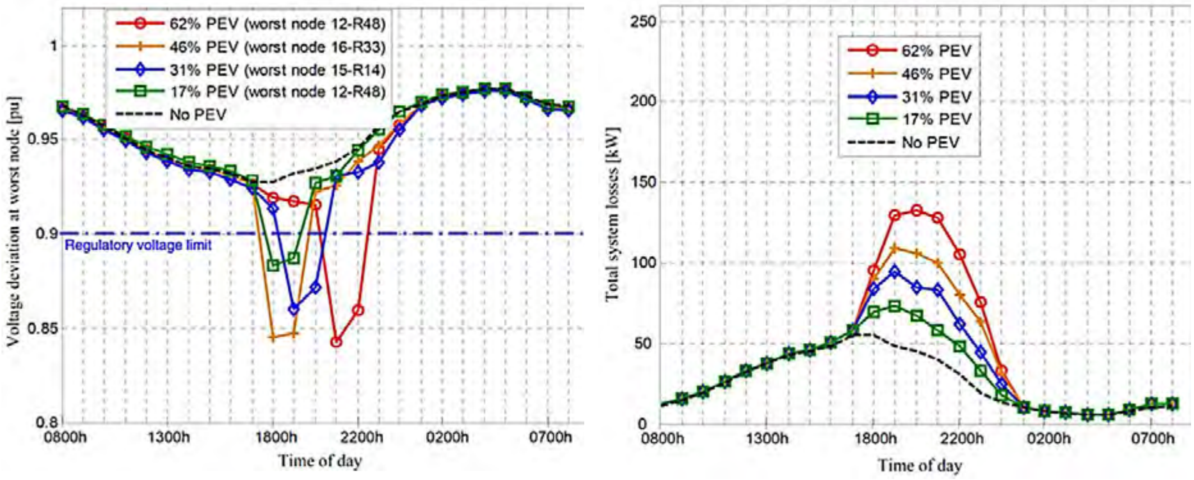


Figure 40: Influence of EV loads on feeder voltage profile [188].

Masoum et al. [193] analysed the impacts of EV charging on the voltage deviation and power loss. This study included four EV penetration levels and three different charging rosters e.g. red (18:00-22:00 h), blue (18:00-01:00 h) and green (18:00-08:00 h). Figure 41 shows node voltage and system losses for charging in blue time zone. As can be seen, the node voltage fell below the regulatory limit and losses increased for all of the uncoordinated charging cases.



(a) (b)

Figure 41: (a) voltage profile and (b) systems losses with uncoordinated charging [193].

EV chargers are power electronic converters with non-linear characteristics. This type of non-linear load is a major source of voltage and current harmonics in power systems. Bass et al. from the Portland State University tested harmonics from EV chargers in [194]. Table 10 shows current harmonics and total harmonic distortion in A phase for a DC fast charger. Current harmonics were as high as 31%, with higher levels at the end of charging when the charging current was lowest. Another study [195] showed that DC fast charging current harmonics were 12 - 24%, while the voltage harmonics were limited within (8.0%).

Table 10: Injected current harmonics from EV chargers measured by Bass et al. [194]

Phase A		**Time in charging cycle (minutes)**			
		2	**7**	**17**	**29**
Harmonics (%)	**3rd**	0.26<51.7°	2.84<-75.6°	6.61<-73.1°	0.87<-56.6°
	5th	0.15<52.4°	2.96<-27.1°	6.27<-16.9°	0.38<-47°
	7th	0.06<38.7°	1.81<-83.6°	4.75<84.9°	0.58<0.9°
	9th	0.06<58.6°	2.28<-31.7°	4.65<-29.5°	0.36<-46.3°
Total distortion (%)		2.2	7.1	15.9	31.2

Harmonics increase heating in the equipment, reducing its life [196, 197]. The study conducted in [198] found that total harmonic distortion should not exceed 25-30% to avoid excessive transformer aging, as shown in Figure 42. Higher harmonics exacerbates this issue. Harmonics can also reduce circuit breaker fault interruption capability. The study presented in [199] showed that ambient temperature, EV penetration level and charging start time impact transformer life most. These issues are expected to become more important when EV penetration exceeds 10%, although this study didn't take into account harmonic content and eddy current loss. Another study presented in [200] concluded that Level 1 chargers have a much smaller impact on transformer life than Level 2 chargers.

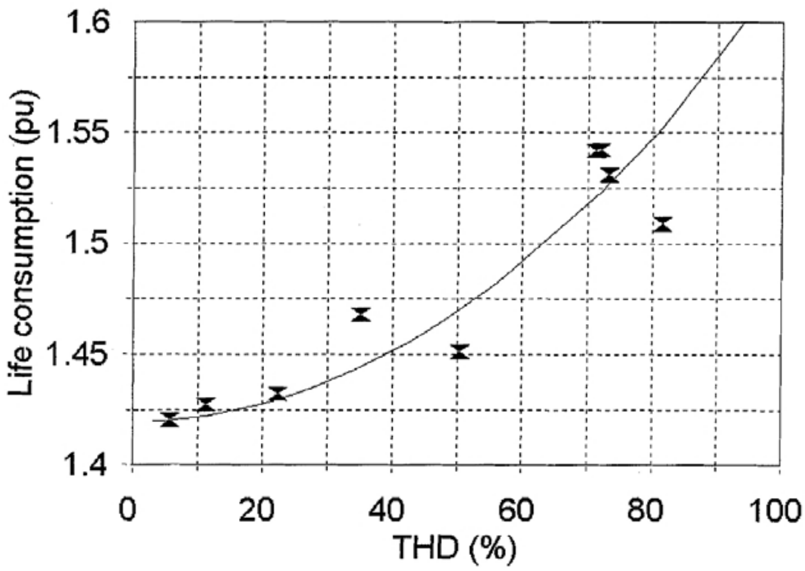


Figure 42: Impact of harmonics from EV chargers on distribution transformer [198]. Reproduced with permission from the copyright owner.

Mitigation strategies

EV charging is flexible, and V2G allows even more flexibility. There are several ways to leverage charging flexibility to manage the issues presented in the prior section. These are illustrated in Figure 43.

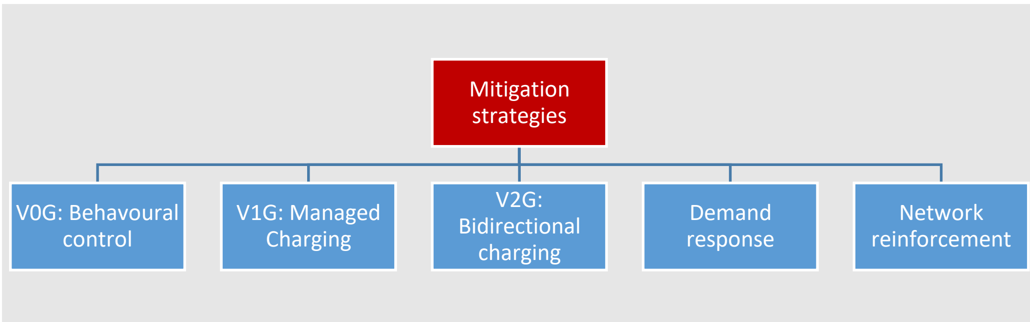


Figure 43: EV charging impacts mitigating strategies.

Smart charging and V2G: Smart charging (with or without V2G) is the most commonly suggested means of mitigating network issues introduced by EVs [186, 187, 197, 201]. This can optimize electricity demand to avoid constraints. Clement-Nyns et al. proposed an algorithm in [201] to minimize voltage deviation and reduce power losses. The effectiveness of the proposed method was validated on a modified IEEE test system with 30% PV penetration. They showed that proposed method can regulate the node voltage almost same as if no EV loads are present. Additionally, line current and peak load demand was reduced significantly compared to the uncoordinated charging. Lopes et al. [202] concluded large scale EVs adoption is possible without major grid reinforcement with advanced centralized control strategies. Smart charging and V2G can assist to increase renewable generation and reduce peak demand. This can also reduce charging cost [84].

V2G fast chargers may also be able to provide reactive support. This can help mitigate voltage issues without discharging the vehicle's battery [85, 126, 127, 187]. This function uses only the DC-link capacitor and grid-side inverter of the bidirectional charger, which means a vehicle needn't be plugged in to provide this service. A study presented in [203] proposed a voltage dependent reactive power injection strategy to mitigate voltage imbalance. This strategy assisted heavily loaded phases without sacrificing the user comfort and showed the effectiveness of this method. Several other studies and trials that shows the effectiveness of smart charging and V2G in mitigating the impacts of massive EV charging on power systems are discussed in Section 3.2.2.

EV charging could be managed in a similar way to PV or other DER. There are several means of doing this under investigation or implemented worldwide. The Evolve project being undertaken by the ANU in Australia is an example of this. This project creates dynamic constraints (“operating envelopes”) and issues them to distributed resources in real time [204].

Consumption tariffs: Consumption tariffs are the most widely used means of modifying customer charge behaviour. This includes Time of Use (ToU) rates and peak demand charges. ToU rates are where energy price varies with time. Traditional this is over a day (e.g. higher price during typical peak times), however may also change in real-time [75, 76] . A well designed ToU rate can shift peak loads to less constrained periods. A NREL study showed the majority of EV loads will shift to off-peak periods if the off-peak price is at least half of the peak price [205].

Non-EV solutions: There will be areas where managing EV charging is insufficient to mitigate constraints. These cases require other action. This could be network reinforcement or demand response such as:

- Onsite renewable energy
- Battery storage
- Relocating chargers to stronger parts of the network
- Increasing hosting capacity of the existing network

Battery storage in conjunction with renewable energy can resolve grid constraints. A study [206] concluded that coordinated PV and battery storage enabled more EV charging in weak grids with severe constraints. Additionally, this system can operate in both stand-alone and grid-connected mode. The commercially available Zappi EV charger optimises EV charge power to match solar generation. Similarly the SolarEdge produces a EV charger that integrates into a solar inverter [33].

Public EV fast chargers can reduce private and commercial charging. This may reduce the detrimental effects of home charging. It also allows customers who don’t have access to off-street charging facilities to purchase EVs. One study by National Grid, UK revealed that 7,000 fast charging locations (7-9 chargers per location) would be sufficient in the UK [109]. Many utility companies around the world are also installing their own networks for EV fast charging stations. For instant, power companies in Germany, such as Vattenfall, E.ON and EnBW, are responsible for 30% of all charging stations. Larger pubic chargers usually require dedicated connection and placement studies. This identifies and mitigates network constraints as well as places them in locations that address the range anxiety [207, 208].

4.3 Socio-technical change

V2G is likely to intersect—and interact—with socio-technical barriers as it moves from its current ‘niche’ to become part of the wider electricity and transport ‘regime’, or system (refer Appendix F). This is not simply a case of technological advancement, nor enough EV owners opting in; it also requires disruption of an existing regime and its underlying policy, politics and power [209].

Although V2G is not a major technical challenge, it must be integrated into EVs and into EV chargers at the design phase, which may have long lead-in times for some vehicle and charger manufacturers. These must then become available on the market, which can be challenging for countries like Australia with small (but growing) EV sectors. The electricity market rules must also allow for the participation of small-scale DER. Grid operators and regulators around the world are, in general, quite risk averse, and this could slow reforms necessary for V2G to participate in the energy market.

V2G is a niche within the emergent EV industry. The electrification of automotive transport will be inherently disrupting to incumbents such as fossil fuel companies, workers, ICE OEMs and associated entities such as dealerships, service technicians, assembly line staff, and suppliers, and traditional energy companies, and may encounter resistance from some of these groups. This may be the case for some OEMs (that may be reluctant to make the investment required for switching); salespeople (EVs currently take longer to sell, take more effort to sell, and are less profitable than ICE vehicles); and independent mechanics (who may lack capacity to retool and reskill) [17],[7]. In addition, taxation of transport fuels may comprise a significant revenue stream to governments, as is the case in Australia, with the potential to create policy resistance [210].

5 Implementation landscape

This section considers the implementation of V2G, organised around four key themes:

1. The technology landscape
2. Markets and policy enablers
3. Potential business models
4. Future trends

In each theme there are multiple factors that can act as headwinds, and/or tailwinds depending on circumstances.

5.1 Technology

V2G is impossible without smoothly integrated technical systems, including cars, chargers, controls and communications protocols, as described in Figure 44. Such hardware and software comes with cost and complexity and is currently only available in limited products.

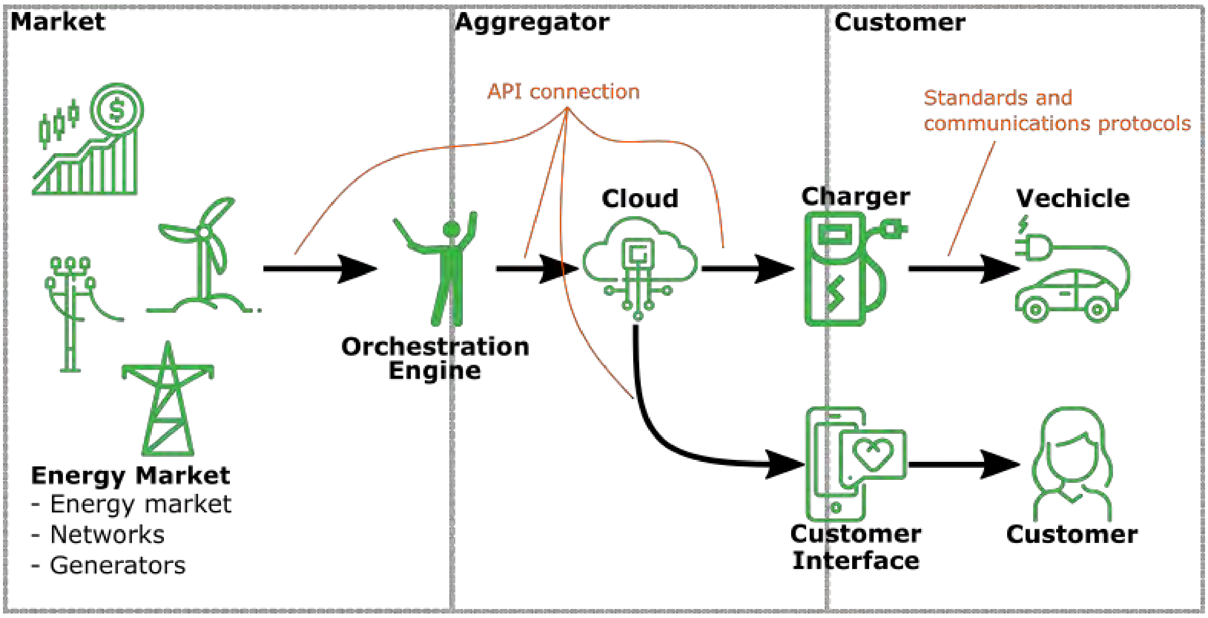


Figure 44: V2G implementation architecture

5.1.1 Vehicle

The key difference between V2G and non V2G cars is the battery management system (BMS). The BMS is responsible for controlling the current flow for both charging and discharging. The main functions of the BMS in EVs are:

- Battery protection – preventing charging and discharging outside of safe margin,
- Power management for driving – including accelerating, braking, idling, etc,
- Battery optimization – managing charging rates and temperatures to maximise the health and longevity of the battery.

To deliver V2G the BMS must be capable of additional power management functions. This will add complexity to the BMS design and increase the possibilities of software errors and sensor faults that may require additional safety measures. Currently, Nissan (Leaf & e-NV200), Renault (Zoe), and Mitsubishi (Outlander) are the only battery electric vehicles that support

V2G technology [211]. Of these, only Nissan allows for V2G within their warranty conditions. Many other car companies are considering V2G – for instance, Honda-Europe and BMW are testing V2G capability [211] – as the popularity of EVs grows and the energy market evolves. V2G capable EVs currently cost more with one source indicating a $1,000 price premium between otherwise comparable V2G and non-V2G vehicles [212].

Currently there are few V2G capable EVs in the Australian market. With little government support for EVs, manufacturers are currently reticent to bring new models to Australia. For example, the Renault Zoe was pulled from sale in Australia in mid-2020 due to poor sales and lack of government support for EVs, despite the Zoe's popularity in Europe [213].

5.1.2 Battery degradation

All batteries age due to usage and time. This means that the amount of energy a battery can store reduces over time. This battery degradation is a major concern for EV drivers [21, 162], seemingly disproportionally to the magnitude of degradation found in studies. To illustrate, one study showed that Tesla batteries retain around 95.6% of original capacity after 50,000 km. Beyond this point, degradation slows down, losing only a further 1.6% capacity after a further 50,000km. After 250,000 km more that 90% capacity remained [214].

Several factors can speed up degradation, including ambient temperature outside the optimum range, charging or discharging at high rates, storing with a high or low state of charge, and the number of charging and discharging cycles. One study [215] suggested EV drivers can extend the lives of their EV batteries by keeping the operating temperature below 35^{o}C, avoiding very high (>60%) DoD, and avoiding charging the car beyond 60%. Battery degradation can be reduced using smart charging or V2G optimised for battery health, particularly in terms of state of charge. However, this is a product of better battery management compared to that provided by a basic charger, rather than a product of V2G per se.

For more details on what factors influence battery degradation and how smart charging and V2G can reduce degradation, please see Appendix A.

5.1.3 Charger

EV chargers come in two different types, as shown in Figure 45:

- On-board chargers – where the AC/DC converter is housed within the EV and the EV connects to an AC power source.
- Off-board chargers – where the AC/DC converter is located outside of the EV and provides a DC power source to the vehicle.

On-board chargers usually have a lower power capacity due to size and weight considerations in the vehicle. Consequently, these chargers are typically much simpler. Off-board chargers do not face strict size and weight constraints and subsequently often have higher power capacities, involving greater complexity. Most vehicles contain an on-board charger and also allow for a DC connection to an off-board charger.

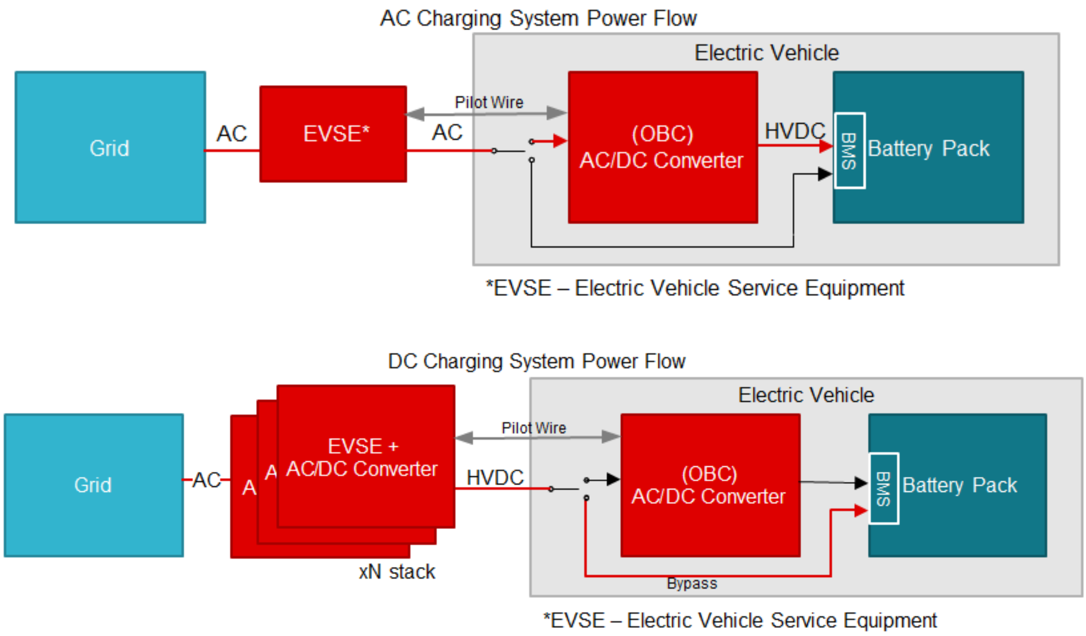


Figure 45: Power flow diagram for AC and DC charging [120]. Reproduced with permission from the copyright owner.

Most chargers are two-stage converters. In the first stage, the AC/DC converter converts the AC input to an intermediate DC output. In the second stage, the DC output from first stage is fed into a DC/DC converter that provides greater control over the DC power flowing to the EV battery.

Both AC or DC charging can support unidirectional (V1G, V0G) and bi-directional (V2G) power flows. More discussion on charger topology is in Appendix A.

5.1.4 Charging standards

There are several charging standards and plug designs currently in use around the world, largely arising as a result of the different countries and regions where vehicles are manufactured. The standards adopted by different carmakers are constantly changing – many carmakers use different charging standards across their range of models.

The main charging standards currently in use are shown in Table 11.

Table 11 EV charger standards

Name	Standard	Location of rectifier	Supports V2G
Type 1	SAE J1772-2009	On-board	No
CCS Combo 1	SAE J1772-2009	On-board and off-board	No
Type 2, Mennekes	IEC 62196/SAE J3068	On-board	No
CCS Combo 2	IEC 62196	On-board and off-board	No – planned
CHAdeMO	C601, IEC 62196	Off-board	Yes
Guobiao	GB/T 20234	On-board and Off-board	No
Tesla	N/A	On-board and Off-board	No

North American standard SAE J3068 is a 3-phase AC charger connector standard. It was developed from IEC62196 annex D and is mechanically identical to it. It extends the standard to support the higher North American 3 phase voltages and higher power levels [216]. This extension includes definition of a data link that can coexist with standard PWM signalling. It (as of 2020) does not explicitly support V2G however V2G has been demonstrated [217] and chargers are available [218] with V2G capability using this connector. A revision of this standard to support V2G has been developed and is planned to be implemented soon. The changes in this standard may be rolled back into IEC62196 in the future.

CHAdeMO was initially proposed by five major Japanese companies as a standard for DC charging, and is the DC fast charging standard used in Japan [219]. It was then included in the IEC61851-23, (charging system and communication) and IEC 62196 standards.

Guobiao (GB/T 20234) is issued by the Standardization Administration of China (SAC) and Chinese National Committee of ISO and IEC to regulate EVs general requirements, communications, and test methods. The Chinese AC charging standard is similar to IEC standards whereas the DC standard is different again [219].

Currently, only CHAdeMo supports V2G. CharIN e.V., the body which oversees CCS, has defined steps of increasingly smart charging toward integrating full grid integration [220]. More details on charging standards, power levels and connectors are provided in Appendix C.

Chargers are also described in terms of levels or modes according to their charging speed, though terminology differs around the world. Level 1 charging usually refers to single-phase power at the standard AC network supply voltage which may be 120 V or 240 V (or thereabouts) and between 10 and 16 A depending on the country. Level 2 charging refers to higher-powered AC charging, for example at the two- or three-phase supply voltage and at higher (up to 80 A) amperage. Level 2 charging usually involves a dedicated circuit and wall box. The distinction can be confusing, as a 240 V charge maybe Level 1 in one country, and Level 2 in another. AC charging makes use of the EV's on-board charger. Level 3 charging generally refers to DC fast charging, and bypasses the on-board charger.

Different terminology may also be used – in general, Mode 2, 3 and 4 charging maps to Level 1, 2 and 3 respectively. Mode 1 refers to a standard power lead as may be used for old EVs and conversions, but in general is no longer used.

5.1.5 Charger installation

EV chargers may be installed at existing or new facilities. These may require a new electricity connection, which will be subject to spatial and electrical constraints such as availability of connection points of suitably large amperage and space to install metering. Cabling costs are driven by physical distance and power needs, and civil works may be required.

V2G chargers are both a generator and a load, much like a stationary battery. This means that utilities need to undertake more detailed assessments prior to connection. Currently utilities may use worst case assumptions. This deterministic process may result in costly network reinforcement for unlikely system configurations [221]. While some connections require significant effort [222], this is expected to be the exception rather than the rule.

Most installation steps for V2G chargers are similar to those for single directional chargers. V2G chargers may require enhanced communications or metering if they are used to provide high speed grid services (such as fast frequency response) or more detailed electrical studies due to their bidirectional capabilities. The core issues however are broadly similar. Residential and commercial EV chargers each have a different set of issues to consider. Chargepoint suggested five key considerations for fleet electrification initiatives [223]:

- Getting all stakeholders involved from the start of the electrification project
- Considering infrastructure and requirements
- Planning physical installation space and charger location

- Considering the functional requirements of the vehicle
- Planning for growth.

These considerations are borne out of the complexity of the installation. Table 12 details some V2G charger installation considerations.

Table 12 V2G charger installation considerations

Issue	V2G considerations
Physical installation location and proximity to parking	This issue is similar for both V2G and single directional chargers. In some cases V2G may require additional data cabling.
Site loading and connection agreements with the local DNSP	This will generally require a more detailed analysis by the DNSP. In some cases grid reinforcement may be required.
Energy pricing, impacts on site demand charges, and billing for energy consumed	V2G increases the complexity of auditing these charges and assigning cost. Billing systems must be able to disentangle revenue from the actions of V2G and EV charging costs.
How revenue is split for VGI services	In some cases single directional chargers may also generate grid services revenue, however this issue is likely larger for V2G.
Conservatism of building mangers	V2G is more complex currently. These discussions may take longer.
Grid connection codes	V2G will require assessment as a generator, which increases the complexity and potentially time taken for this step.

Most residential EV charging happens at home. The hardware used depends on the car and the customer's driving habits. The simplest is to simply use the "Level 1" charger that plugs into a standard power point and comes with the vehicle.

VGI require a more advanced charger, which are generally an additional cost. In some jurisdictions there are incentives to install smart chargers, however these usually do not provide additional subsidies for V2G. For example, the UK Electric Vehicle Homecharge Scheme (EVHS) provides grant funding of up to 75% towards the cost of installing electric vehicle chargers at domestic properties across the UK. This scheme requires smart charging, however does not provide additional subsidy for V2G [224].

It is unclear how customers will elect to install V1G or V2G chargers. There is currently a high level of uncertainty about returns and few incentives, especially in the case of V2G. Most current V2G projects provide a charger as part of participation, subsidised by grant funding.

In the future V2G chargers may be built into the vehicle. This reduces the need for specialised hardware at the charge location to enable V2G. In these cases, V2G may be controlled through vehicle telematics. How vehicle-mounted V2G capability operates with DNSP requirements is unclear.

5.1.6 Software

Software is a less visible but equally critical dimension of charging infrastructure. These systems control and coordinate the actions of chargers. Optimisation algorithms are responsible for providing services to both customers and the energy system.

EV owners have many drivers for EV/V2G use (see 3.1). Each customer will have a unique profile and set of preferences, both of which may change over time. Optimisation algorithms must manage these diverse needs, or else customers may lose trust in the optimisation and withdraw their consent. Commonly the customer controls EV charging through two means:

- Preference information (e.g min/max state of charge, when the vehicle is required)
- Controls (e.g. “charge now” or “boost”) [171, 172].

Energy system organisations also rely on optimisation for services. Different participants in the energy system may have different drivers and needs (as discussed in 3.2 and 4.2) which may conflict at times. Often V2G EVs are combined with other assets such as distributed storage to form a virtual power plant [86].

The optimisation of V2G power system services has been subject to considerable research, which includes economic, battery degradation, and other considerations [225, 226]. To date, few of these optimisation algorithms have been deployed in real-world settings with the main research emphasis being placed on the theoretical advances. Privacy and security of the large amount of data is also important for successful deployment of V2G.

5.1.7 Metering

Smart meters are an essential cornerstone of smart grids [227]. A key characteristic of demand response, as opposed to consumption, is that it cannot be measured directly [228]. Traditionally demand response is measured using a baselining methodology.

Baselining involves measuring consumption doing the demand response interval and comparing it to demand at other times. The response provider is then paid based on the difference [228]. For EVs, this methodology is likely to be used to control for customer charging behaviour and for consistency. Baselining requires accurate metering data, as the measured response directly impacts the payment customers receive.

Australia has a small but increasing penetration of smart meters. Victoria currently has the highest penetration of the states and territories due to their 2009 smart meter rollout [229]. In the rest of the NEM smart meters are installed as new and replacement meters.

5.2 Markets and policy

Market settings and policy measures are key enablers to V2G uptake. They are key to lowering barriers to entry and ensuring value can be traded and realised easily. In this section we present the types of relevant reforms and policies, including current conditions, international examples, and known trajectories. These issues will be further expanded upon in Chapter 6, where our discussion will shift to recommendations.

5.2.1 Market reform

The key regulatory features identified in the literature as strong influencers of V2G viability are:

- dynamic pricing,
- the presence of settings that discourage participation (including taxation),
- clarity in the roles of aggregators and DSOs, and
- market recognition of demand-side response measures.

A recent study asked 227 transportation and energy experts in Nordic countries what policies could accelerate V2G uptake [230]. This study suggested the most important changes would be to remove market barriers, such as embracing more dynamic prices, ensuring taxation and regulatory settings did not discourage participation, and ensuring the roles of DSOs and aggregators were clear. This paper indicated that in Denmark, V2G participation was taxed heavily, which was a barrier.

Uptake of V2G will depend on the realisation of as many value streams as possible. As shown in Chapter 3, no one organisation can realise all value streams. This means that there needs to be a clear framework for valuing and transacting these services. Without this, some value streams may not be realised. For example current V2G demonstration projects have tended not to focus on DSO services because the value and service specifications for distribution services have not been clear [2].

V2G is a form of demand response. This means that the regulatory market requirements are similar to other forms of demand response, such as electric heating and cooling [230]. Australia is currently undertaking a consultation to redesign the market to enable greater levels of demand side participation. This work may create a two-sided market where demand and generation participate in the market equally [231], building upon a recent rule change that enables large customers to participate in the market.

The value of demand response can be translated through a variety of means. In its simplest form this may be through the design of tariffs. These tariffs can be levied by networks onto retailers and/or by retailers on to customers [232]. Traditionally these prices are non-localised and static in time to reflect general network loading, for example time-of-use energy rates are designed to reflect afternoon-evening peak loading on the network. This same approach can be used to target EVs, as has been done by retailer PowerShop, who offer a specific EV time-of-use tariff [233]. There are also examples of more dynamic structures such as ERCOT's "4CP" critical peak transmission pricing in Texas, in which distribution networks are charged based on their consumption during the four peak times in June, July, August, and September. These charges motivate the distribution networks to reduce the load in their networks at these times, which they may do through their own tariffs or through other means such as demand response programs, such as Austin Energy's "EV360" time of use EV charging tariff [113].

Markets are another means of valuing demand response. These may be in addition to tariffs and offer a more dynamic and locational means of valuing demand response. Internationally there are several examples demand response valuation mechanisms (Table 13).

Table 13 Demand response valuation mechanisms

Location	Product	Description
UK	Flexible Power (Western Power Distribution) Distribution system management **Operational**	A location where Western Power Distribution advertises network constraints to demand response providers. Demand response providers can provide pre fault, post fault, or system restoration services.

Location	Product	Description
UK	Piclo Flex (UK Power Networks, Scottish & Southern Electricity Networks, Western Power Distribution SP Energy Networks) Distribution system management **Trial**	Piclo Flex is an energy flexibility exchange. It is in the pilot stage with for distribution network operators and over 200 flexibility providers. Providers can advertise pre and post fault demand flexibility services.
CA, USA	Demand response and load participation (California ISO) Day ahead and ancillary energy services **Operational**	The California ISO encourages demand side participation in the Californian energy market. There is an initiative in progress to enhance the ability of DER to participate, including EVs. This enhances the ability of storage to participate [234].
TX, USA	"4CP" transmission pricing (ERCOT, Texas) Transmission pricing **Operational**	While not specifically aimed at enabling demand response this pricing method gives a string signal to Texas market participants to reduce demand at critical times. This short, (4 x 15 minute periods) and strong ($45,000/MW/year [235]) price signal leads to a number of programs that aim to reduce "4CP" liabilities. This includes the "SHINES" and "EV360" initiatives by Austin Energy. Large customers may be directly exposed to 4CP pricing [235].
EU	EU Interflex (EU) Distribution system management **Trial**	A project that investigates the use of distributed resources to manage distribution network constraints. Ran through 6 demonstrators in The Netherlands, Germany, Czech Republic, Sweden, and France. Demonstrations included local markets and direct DSO control [236].
AU NEM	Two sided markets (Energy Security Board) Demand side participation in energy markets **Investigation/Concept**	An investigation of the appropriate model for creating a market where load participates equally with generation. Currently investigating the use of day ahead markets.
AU WA	100MW challenge (Western Power) Increase in minimum demand to offset impact of solar DER **Trial**	This project aims to increase minimum demand through procuring additional load during high solar/low demand periods. Capacity is procured using flexible power contracts with partners (such as large loads, generators, or aggregators)
UK, Sweden	Nodes Market A demand response exchange **Trial**	Nodes Market operates as a trial in several locations. NODES is a universal platform for local, flexible electricity markets with features allowing for connecting to other markets [237]

Where clear pricing signals exist, commercial providers can more easily offer products. For example, Enel-X participates in demand flexibility markets in the US with a fleet of their of their JuiceBox Pro 40 chargers and provides the value back to customers as reduced subscription fees for financial rewards [238]. Similarly OVO Energy's "Project Scurius" involves 1,000 V2G

EV chargers providing services to both the market and distribution network (UK power networks) [118].

A large uptake of EVs could lead to significant amounts of supply entering grid services markets. One report predicts 2.8 GW of maximum PEV demand in Australia by 2040 [20]. This will likely cause a significant impact on the realised value of services, examples of which have already been seen in relation to solar PV and wind generation in Australia [239], and which may be exacerbated in small markets like FCAS.

5.2.2 Non-market policies

Policies outside of market frameworks may also be effective in removing barriers and incentivising involvement in V2G. Commercially available V2G products are currently few and far between, meaning that policies need to focus on bringing V2G to the market and building acceptance among potential users.

In broad terms, V2G sits within the demonstration and early deployment phases of commercialisation in different parts of the world. In Australia, V2G is at a point of pilot-scale demonstration projects. The Nordic study raised in the previous section emphasised the value of demonstrations and supporting start-up companies and pilot projects [230].

Policy may also have a role to encourage adoption for V2G hardware. Some jurisdictions have existing schemes in place to encourage smart chargers. In the UK, all chargers installed under government funding schemes for domestic chargers must be smart [240].

The non-economic barriers to users set out in Section 4.1.1 relate to the unknown impacts of the technology on utility, lifestyle and the vehicle. This information gap in people's understanding of V2G needs to be addressed before they might seriously consider it. However, a preceding step must be to raise awareness of the existence of V2G in the first place.

Need for targeted information and user co-creation

A consistent theme across all studies is the need for more awareness of V2G and its benefits, and more opportunities for people to experience (and shape) the technology. Wider strategic awareness of V2G and its potential role in the energy system will be critical. Improved basic energy literacy would be valuable in this regard, and might also help address wider issues of disengagement from the energy system. In addition, V2G users will need detailed operational awareness of how/when V2G aggregation will work in their circumstances.

Appendix F describes two key roles in uptake of new technologies:

- **User-legitimators** develop new use cases for a technology or product
- **User-citizens** uptake new technologies and lobby for changes to enable more value from it.

In developing messaging, governments, EV OEMs and dealers, and V2G aggregators should consider which user 'roles' they are targeting – user-legitimators or user-citizens – as different groups will require different messages. It may be worth targeting user-legitimators/opinion leaders, such as can be found in EV associations, clubs, magazines, as they can 'play a disproportionate role in legitimizing technology' [7, p. 156].

Most users are likely to respond well to information on the benefits of V2G, such as services to the grid, or improved health from additional renewable electricity integration. This information could also help embed new scripts for V2G. However, it might also invite a rhetorical reaction from others, and so care is required. Other, less altruistic messages may also be worth promoting, such as V2G and EV as conspicuous green goods.

Information on potential V2G revenue is also worth highlighting, but given people's tendency to discount future savings from energy, messaging should emphasise value (e.g. the incremental cost of a V2G-capable EV, or an upgraded charger) over dollars profit. Messaging could also emphasise the relatively low costs of V2G participation in terms of time use and battery degradation.

The perceived challenges of V2G will likely not be addressed with information alone. There is a clear need for more V2G visibility, including through pilot projects, which should involve users wherever possible. And it will also be important to 'get beyond' pilots and narrow conceptions of user experience: governments, OEMs, dealers and aggregators should also actively encourage environments where users can 'tinker and reinvent' [7, p. 177].

Co-design for convenience and user/societal benefits

It is also clear from our review that work is needed to maximise convenience and flexibility for V2G owners—at a range of levels. At the end-user level, aggregators should focus on flexible remuneration schemes such as earn-as-you-go or up-front payment over fixed contractual terms, and EV battery availability at times that are convenient to them. More fundamentally, however, meaningful engagement/co-design will be required at a much earlier stage to ensure people's needs and aspirations are well understood and reflected in V2G scheme design.

At the same time, it is important that V2G's technical issues, particularly around cybersecurity, data privacy and autonomous decision making are considered carefully and resolved ethically, in a way that maximises benefits for users and wider society, and that manages attendant risks. As with V2G scheme design, for this to be successful this process must be done in a participatory manner, with the genuine involvement of users as well as consumer advocates and other, diverse experts.

Finally, it is important to remember that V2G and EVs do not exist in a vacuum—future V2G and EV policy development should have regard to wider transport, energy and climate policies. This will help to realise the many benefits of V2G technology, promote equity, and avoid unintended consequences. Future policy and research should also be alert to wider system and political issues, for example of incumbency and resistance, and more work will be needed to develop appropriate 'just transition' policies and address issues of power relations: 'the question of who will be doing V2G, and how these benefits will accrue' [7, p. 53].

5.3 Business models

For V2G to become a commercial service, it must be integrated into a viable business model. Such a business model must deliver V2G at scale, pooling together the capabilities of a large number of vehicles into a joint energy resource. This is such a critical step that it is typically described as being performed by a dedicated "aggregator", although we emphasise that a wide variety of stakeholders could play this role. The role of an aggregator can be thought of as the inverse of the role of electricity retailer:

- Retailers manage market price risk to present firm products to end-use customers
- Aggregators manage delivery and technology risk of demand response and present firm products to the energy market

Aggregators act as service providers to other market functions. They abstract resources and customer preference from the market and present them in terms that meet the market needs. Their roles include [177]:

- combining many small resources into a larger group that is sufficiently large to provide services to the market
- combining multiple value streams into a single one to present to customers
- managing uncertainties and risks.

Aggregators risk management role serves both their customers and the market. They group a large number of low certainty services from EVs into a single high certainty service for the market. The extent to which this is required depends on the risk appetite of the aggregator's customers. Over time it is expected that aggregators will be able to better manage this risk through diversity of sources and operational experience. How aggregators fit between the energy market and customers is shown in Figure 46.

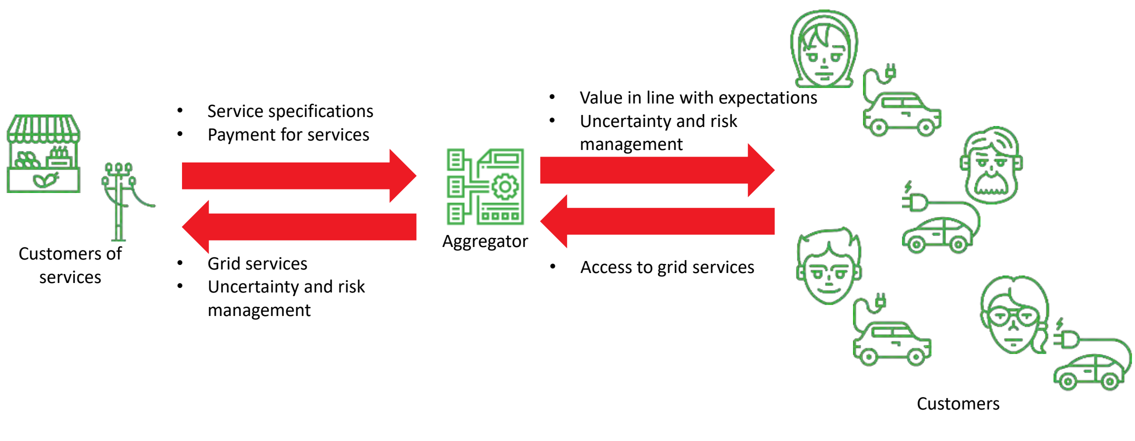


Figure 46: Role of aggregator.

5.3.1 Potential aggregators

The aggregator role is required to realise value but is also the least well defined. It sits in a newly-created space between the electricity network, market and customer, and could credibly be provided by several different actors. A report by BestRES investigated business models for aggregators of small generation resources and demand response in Europe [241]. It posited six business models, reframed for the Australian context in Table 14. These are described in more detail in Appendix B.

Table 14: Potential aggregator business models (adapted from [241])

Model	Explanation	Example
Combined aggregator – retailer	A retailer acts as an aggregator	Octopus Powerloop (Octopus Energy)
Combined aggregator – market participant	An aggregator who is a market participant, separate to the customer's retailer. There are two participants per connection point (retailer, aggregator)	JuicePlan (Enel-X)

Model	Explanation	Example
Combined aggregator – DSO / Distribution network	Distribution network acts as aggregator. This arrangement would not comply with ring fencing rules in Australia and hence would not be allowed, however is acceptable for trials.	Electric Nation (Western Power Distribution)
Independent service provider	Aggregator is a service provider for another market actor	SwitchDin (Load control)
Independent aggregator	Aggregator sells services to another market participant (e.g. retailer)	Reposit Power (Distributed storage)
Customer as aggregator	Customer acts as their own aggregator. Likely only possible for large customers	University of Queensland (Virtual hedge using centralised battery)

These models are not exhaustive and others exist. For example prospective rule changes such as multiple trading relationships as proposed by the Energy Security Board in their *“moving to a two-sided market”* consultation [231].

There are several organisations that may step into the aggregator role, both from transport and energy sectors. Appendix B includes a description of adjacency factors that may be relevant for aggregator business models.

5.3.2 Cost stacks and operating costs

There are several classes of costs for aggregators to operate, including:

- Customer acquisition and retention
- Technology
- Regulatory and commercial [177]

Customer acquisition and retention is a very important function for aggregators. They can only provide service to the energy system if they have sufficient numbers of customers. These costs will be made up of advertising, incentives, and customer engagement.

There may also be significant technology costs for aggregators. They must integrate customer-side technology with energy market systems and processes. Some models may also be capital intensive. These costs may include hardware and software.

Regulatory and commercial costs depend on the requirements of the jurisdiction. It may include insurance, liquidity provisions, transaction costs, etc.

Many of these costs may be fixed (i.e. one per aggregator). This means aggregators may have significant economies of scope or scale benefits. This may indicate that the most efficient (from a cost point of view) arrangement is for a single aggregator to provide all service in a region. Multiple aggregators however can help promote innovation or reduce risks stemming from a single aggregator’s market power [177].

Enablers that can assist in the viability of aggregators have been studied by IRENA and are listed in Table 15.

Table 15: Key enablers for aggregators [242]

Category		Requirement
Technical	**Hardware**	• Controllable Hardware such as V2G EVs (5.1) • Metering (5.1)
	Software	• Aggregation and optimisation software (5.1) • Real-time communication (5.1) • Forecasting models (5.3)
	Communication	• Standard protocols (5.1)
Regulatory	**Wholesale market**	• Permissive regulatory environment (5.1.7) • Clear price signals (5.1.7) • Regulations encouraging smart metering (5.1.7)
	Distribution	• Local markets for DSOs to procure grid services (5.1.7) • Data collection, management, and sharing rules (0)
	Energy retail	• Dynamic pricing (5.2.1) • Open and innovative retail market (5.2.1) • Clear roles & responsibilities for market participants (Appendix B)
	System operation	• Define rules for co-ordination between distribution and transmission operators (5.3)
Stakeholders and responsibilities	**Aggregators**	• Open transfer of information to DSOs of location, capacity, and type of resources (5.1.7)
	Distribution System Operators	• Ensure a level playing field for all flexibility providers (5.1.7) • Procure flexibility from providers (5.1.7) • Securely share data as per privacy norms (0) • Forecasts of services and past performance (5.3)

5.3.3 Bringing it all together: value stacking

An economic V2G value proposition likely stacks several of the benefits as described in Chapter 3. An aggregators role is to do this stacking.

To adequately value stack, aggregators need to:

- Be able to adequately forecast resources that can be provided
- Co-optimise multiple value streams.

Aggregators need insight in the future availability of the flexibility resources they aggregate to maximise the value they can stack. Generally, predicting behaviour is easier for larger numbers of assets. The wider energy market operates across states therefore require aggregated state-based forecasts. Distribution services markets are more complex to forecast because they require highly localised forecasts of constrained sections [243].

Usually aggregators will be co-optimising several value streams. Each value stream requires a different dispatch profile. Some markets may be mutually exclusive where they both have different dispatch profiles. For example, one study found that day ahead and real time market participation were not compatible as they both required bulk energy to be shifted in and out of the battery [244].

5.3.4 Impact on other energy market participants

V2G EVs will compete with other service providers. This will reduce the value of these services due to competition. The extent to which V2G impacts these other providers will depend on the relative cost stacks of the technology and the size of the market.

As shown in Appendix E, frequency control services are currently the largest energy market value stream for batteries. The FCAS market however is relatively small and large numbers of EVs would reduce prices in this market and the realised values significantly. For example, the Hornsdale Power Reserve battery reduced the value of FCAS services by $116m in 2019 [103] even though it has a capacity of only 100 MW (around 14,300 EVs).

Future value risks such as these can increase the difficulty in financing for new projects [245] and may cause revenue reductions for others.

5.4 Future trends

5.4.1 EV Uptake forecasts

The uptake of EVs has been accelerating all over the world significantly. According to the International Energy Authority, the worldwide stock of electric passenger cars in 2019 reached 7.2 million, an incremental increase of 40% over the previous year. It is reported that more than 2 million EVs were sold until 2019, just after two years of crossing the 1 million mark in 2017. Sales increased approximately 14% in 2019 compared to 2018. China is the largest EV market (1.06 million sold in 2019) followed by the Europe (2nd largest) with 561,000 units sold in 2019 and USA (third largest) with 323,000 units sold in 2019. In addition to this, almost 377,000 light commercial electric vehicles were on the road in 2019 [246]. The cumulative sales of electric buses and trucks were around 513,000 and more than 12,000, respectively in 2019. It is projected by IEA that nearly 14 million EVs will be on the road in 2025, while this will reach 25 million in 2030. They also mention that global stock of EVs will increase to 50 million by 2025 and close to 150 million by 2030 [247].

In Australia, the uptake of EVs have been modest compared to international trend. A total of 6718 EVs were sold in 2019, an increase of 203% over 2018 [248]. In the first half of 2020, around 3226 EVs were sold despite global pandemic. One study conducted by ENERGEIA for AEMO forecasted that there will be 2.56 million EV on the road by 2036, reaching to 13.6 million by 2050 [249].

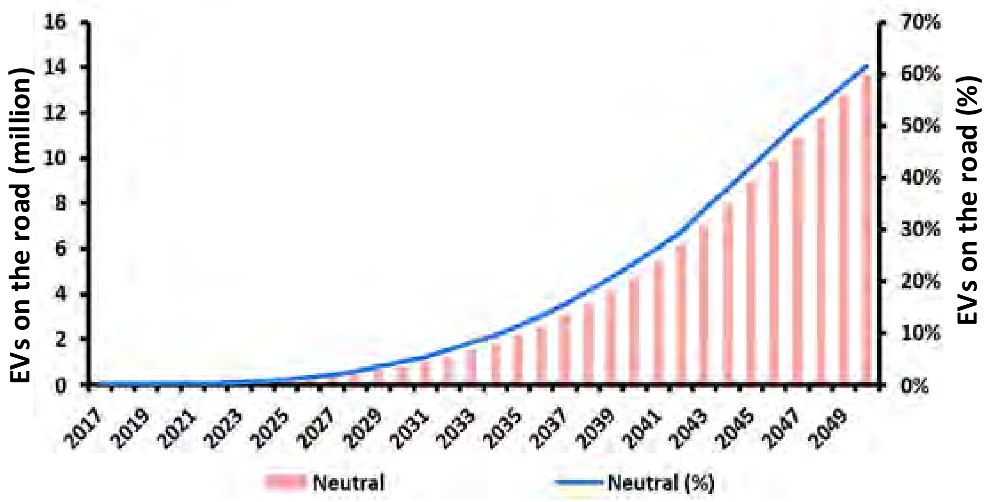


Figure 47: Forecasted EV sales in Australia [249]. Reproduced with permission from the copyright owner.

The Bureau of Infrastructure and Transport Research Economics (BITRE) modelled EV uptake based on predictions of vehicle price and fuel cost. They predicted Australian uptake as shown in Figure 48. This graph shows a predicted "raw" EV uptake (based purely on price) and a "cost" uptake curve which is based on the purchasing preferences of early adopters.

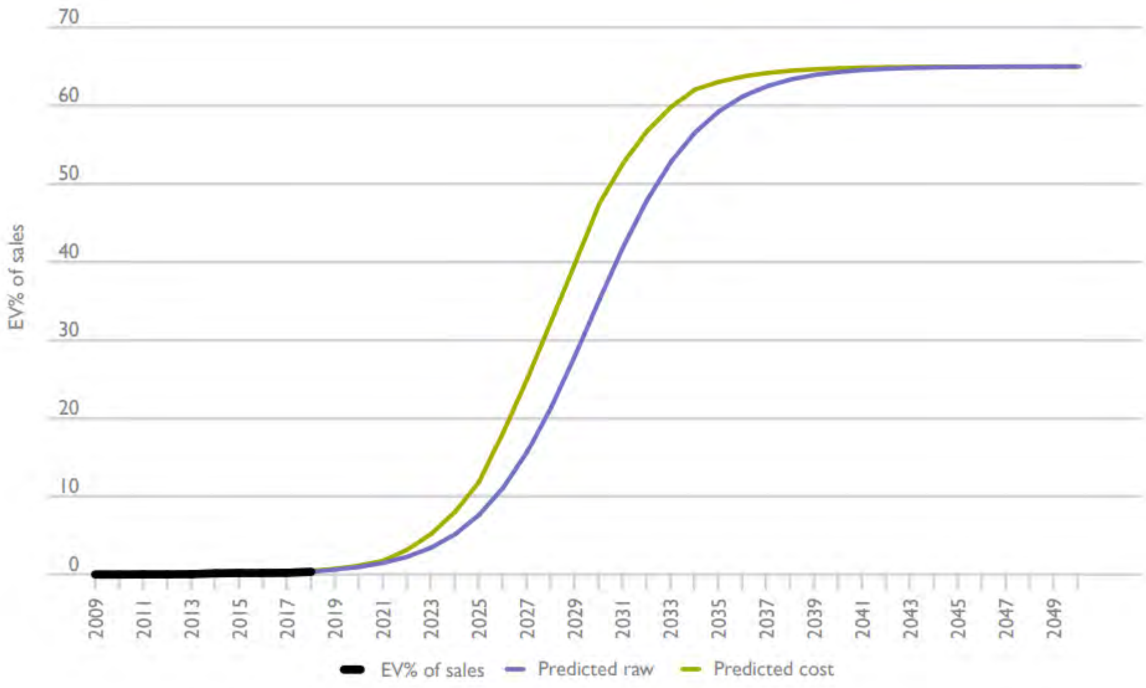


Figure 48: Forecasted EV uptake in Australia by BITRE [250]. Licensed under Creative Commons.

There are few forecasts of V2G uptake. This, coupled with the very low uptake of V2G-capable chargers currently, leads to a lot of uncertainty in future V2G uptake.

V2G requires two capabilities, which can be individually estimated to gain an understanding of potential V2G uptake. These capabilities are:

- A charger and vehicle that is capable of V2G
- Manufacturer warranty support

Currently the only vehicle in Australia that supports both of these is the Nissan Leaf. At the hardware level, other CHAdeMO-equipped EVs support V2G, however using this capability may void the manufacturer's warranty. In Australia only Nissan and Mitsubishi use the CHAdeMO DC charging standard [251]. In the future other vehicles may support V2G. For example Hyundai's recently announced Ioniq 5 will have "Vehicle to Load" (V2L) capability as standard [252].

Energeia's 2018 Australian EV market study forecasts total EV uptake and manufacturer market share [20]. An estimate of V2G "addressable market" (number of V2G capable, manufacturer supported EVs) is shown in Figure 49. There are three assumptions shown in this figure:

- Nissan remains the only manufacturer of V2G-capable and supported EVs

- Nissan and Mitsubishi (who support V2G at a hardware level) support V2G
- All manufacturers except Tesla (who have stated they will not support V2G) support V2G

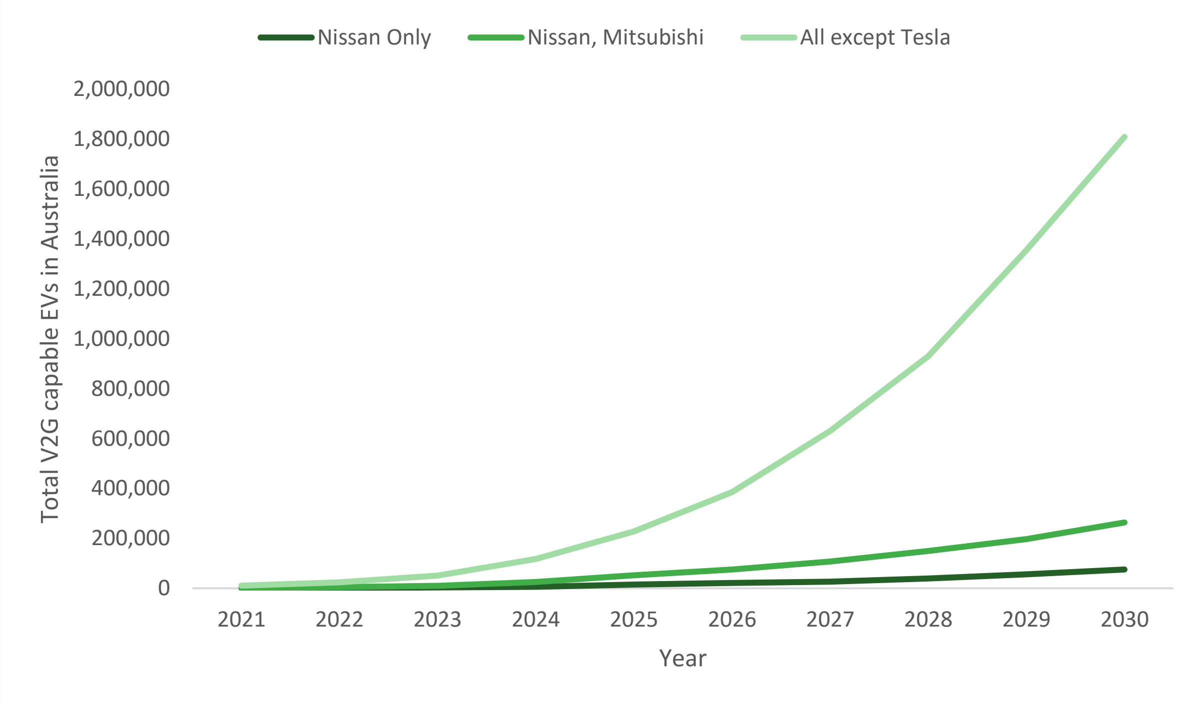


Figure 49 V2G capable vehicle uptake forecast

As discussed in 3.2 relatively small numbers of EVs can provide significant amounts of service, particularly for frequency control. Based on Energeia's analysis [249] by 2021 there will theoretically be enough EVs in New South Wales to provide a similar level of frequency control services to the Hornsdale battery in South Australia, assuming all EVs were V2G capable and enabled for this service.

5.4.2 Battery technology

The cost of battery for EVs is reducing as the technology is advancing and production is increasing. Bloomberg have stated that battery prices decreased from US$1100 per kWh in 2010 to just US$156 per kWh in 2019. They also predict that cumulative demand will exceed 2 TWh in 2024 and the price will be reduced to US$100 per kWh. This cost reduction will likely be achieved through new pack design, decreased manufacturing capital investment and changing supply chain [247].

The most common battery type in EVs is the lithium-ion battery. The last decade has seen significant progress in the various elements of lithium-ion batteries, such as lithium metal anode, cathode, electrolytes, and catalysts that have increased energy density and life cycles. One study showed that new cell design could increase cycle and calendar life up to ten times compared to the current technology [253]. Recent development has focused on removing intermediary module components to reduce pack cost and increase energy density [254].

As concluded by IEA, the EV market is likely to be dominated by Li-ion batteries in the next decade. The reasons behind this are: (1) well establish technology (2) huge investment and (3) lower readiness level of alternative technologies. However, some alternative battery chemistry technologies, such as lithium-metal solid state, lithium-sulphur, sodium-ion, and lithium-air (which shows better performance than Li-ion batteries) are at various stages of development and might be available for commercial use after 2030 [247]. Among these chemistry technologies, lithium-metal solid state batteries are the most promising near-term prospect as the technology has been proven with large prototypes. A group of researchers from Samsung developed a prototype of lithium-metal solid state battery that exhibits high energy density (>900 watt hour per litre) and superior cycle life (>1,000 times) [255].

5.4.3 Autonomous vehicles

Autonomous vehicles are being developed. These vehicles may change vehicle ownership and usage models towards mobility as a service [256]. This would likely change the value landscape significantly. On the one hand, users of mobility services may be less concerned with the vehicle providing grid services and service providers will want to reduce their cost bases as much as possible. On the other hand, higher utilisation of autonomous vehicles may reduce the opportunity for vehicles to provide grid services.

5.4.4 Scope of vehicles

Many V2G projects have focused on light vehicles so far. Commercial vehicles (such as busses and trucks) are a potential large demand response resource. Some projects are beginning to look at these vehicles such as Bus2Grid in the UK which will fit V2G capability to 28 buses [257]. Similarly V2G school busses have been trialled in California [258]. These vehicles can have significantly larger batteries than light vehicles and hence could offer significant capacity. The Bus2Grid project will offer over 1MW of capacity into the grid [259].

6 Recommendations

This document has reviewed V2G experiences around the world, presented in as benefits, barriers, and enablers. Based on this survey we can recommend actions that will enable smoother uptake of V2G in Australia. Recommendations fall into four themes: standards and rules, customer value proposition, open value transfer, and fostering an industry. Within each theme we recommend actions falling into three groups:

- Actions for **immediate** implementation,
- Actions that are being **explored during the REVS trial**, which we will provide specific next steps for in our final report,
- Actions that we expect will be required in the **future** but whose precise form requires further work to define.

6.1 Standards and rules

V2G will see the most uptake when there are clear standards and rules around its usage. At the nexus of transport and energy, EVs face a unique set of rules – those for transport must work with those for energy. In other dimensions, as a form of demand response, V2G has a lot in common with distributed storage, PV, and other forms of demand response.

At this nascent stage of V2G it is important to "right size" rules. We must strike the balance between allowing V2G to deliver value and risk management.

Table 16 Standards and Rules recommendations

ID	Action type	Who needs to act?	What do they need to do
1.	Immediate	Standards bodies	Ensure grid connection standards (e.g AS/NZS 4777) are not a barrier to V2G. Standards must: • Recognise V2G and allow for its specific use cases • Coordinate with vehicle and international standards to avoid conflict and harmonise where possible.
2.	Immediate	DNSPs	DNSPs are central to enabling value from V2G. DNSPs should: • Implement dynamic connection point constraint technologies to replace today's restrictive constraints and enable easier market participation of V2G. In the future this may also require constraint forecasting to enable easier market participation by DER. • Ensure connection processes for V2G are transparent to market participants and customers and are stable and smooth • Harmonise connection processes across DNSPs • Ensure that rules and bilateral demand response agreements recognise and encourage value stacking.

ID	Action type	Who needs to act?	What do they need to do
3.	REVS	AEMO/energy regulators	The national electricity rules requirements can be a barrier to grid services from distributed resources, including V2G. Rule makers can encourage uptake by: • Ensuring technical requirements are fit for purpose and not onerous for distributed resources. For example, this may include lowering participation thresholds below 1MW. • Ensuring rules do not penalise energy storage (devices that can charge and discharge) • Recognising the resilience benefits of V2G.
4.	REVS	DNSPs/research institutions	Engage proactively with V2G to leverage Australia's success with DER integration by extending existing DER constraint management products to include EVs and V2G. These products can then be exported worldwide.
5.	Future	Standards bodies	Influence international standards as they are reviewed to harmonise with Australian standards and allow for Australian use cases. In particular this includes charging standards (such as those managed by CHARIN).

6.2 Customer value proposition

V2G can only succeed if customers see value in it. This requires it provide additional services they value, while not impinging too much on their vehicle's mobility uses.

Table 17 Customer value proposition recommendations

ID	Action type	Who needs to act?	What do they need to do
17.	Immediate	Trial proponents	A key part of normalising V2G is sharing use cases and building a compelling narrative for V2G. EV/VGI projects can help this process by ensuring development and communications activities include end users. For example, bringing end user feedback into demonstration programs, or developing comms with end users in mind.
18.	REVS	Governments and industry	Consider targeted information campaigns to inform individuals, fleets, and car dealers about V2G and address perceived risks, such as range anxiety and battery health. These programs may work in concert with general DER/grid participation education programs.
19.	REVS	Energy and transport industry	Enhance uptake and broaden appeal of V2G by identifying and then appealing to a more diverse range of customer value drivers (not just financial).
20.	Immediate	Users	Private and fleet EV owners interested in V2G should engage with industry and governments to make visible their interest, and participate in trials and initiatives.

6.3 Open value transfer

A key property of jurisdictions which have picked up V2G strongly is that they have mechanisms to make the value of V2G apparent. This can be through markets (such as the demand flexibility markets of the UK or California), real-time pricing (such as explored by Sacramento Municipal Utility District), time of use tariffs (such as those tested by Austin Power), or other means. These mechanisms serve as a signal to customers or aggregators to encourage EVs to respond to energy system needs.

Table 18 Open value transfer recommendations

ID	Action type	Who needs to act?	What do they need to do
21.	Immediate	Energy industry and regulators	Cost reflective pricing is a proven means of incentivising EV charging at times which avoid network congestion. This can be a staged approach: • In the short term expanded use of “time of use” energy and demand tariffs can shift EV charging outside of peaks • As V1G/V2G reduces in cost and aggregation becomes more widespread, dynamic and localised price signals can manage congestion
22.	Immediate	Energy and transport industry	Ensure that grid services customer contracts align with customer’s transport values. For example, this may mean avoiding plug in targets that appear punitive.

ID	Action type	Who needs to act?	What do they need to do
23.	REVS	Energy industry and regulators	Flexibility from V2G can provide services to existing energy markets as well as potential future distribution services markets. The REVS trial will demonstrate V2G providing FCAS services. For these services to expand beyond the trial existing barriers need to be removed or new markets created to transact the value. • In the short term remove barriers preventing V2G participating in the market where possible. This includes: o Minimum participation volumes o Metering requirements o Interaction with the distribution system and constraint management • In the longer term investigate distribution flexibility markets

6.4 Fostering an industry

V2G grid services may be provided by a diverse group of existing and new-entrant organisations. Many of these will not have experience in the energy system and may require additional guidance.

Similarly, for a small market such as V2G is important that new technologies and concepts developed elsewhere can be imported and proven easily and quickly.

Table 19 Fostering an industry recommendations

ID	Action type	Who needs to act?	What do they need to do
24.	REVS	Governments and funding bodies	Trials and demonstrations (such as REVS) are a key part of de-risking new business models. These trials must generate actionable outcomes to relevant issues.
25.	REVS	Governments	Consider short term funding programs to reduce the cost delta between unmanaged, managed, and V2G chargers. Electrification of government fleets and adopting managed and/or V2G charging would be powerful actions.
26.	REVS	Industry, regulators, and governments	V2G and grid services requires collaboration of energy and transport sectors. Similarly, services may be provided by new entrants who have little previous expertise in the energy sector. • Create and foster cross-industry collaboration to build connection between transport and energy industries. • Create mechanisms to educate and build relationships with new entrant grid services organisations

ID	Action type	Who needs to act?	What do they need to do
27.	REVS	Energy and transport industries	Import and validate overseas technologies to increase choice and drive down cost in the market.

6.5 Government policies

In section 5.2 the existing policy agenda for V2G was outlined. Policy instruments can broadly be categorised as being through advocacy, networks, money, government direct action and law [260], though not all may be relevant to a particular problem. In this section, we state the case for government action and make recommendations for relevant actions to support the commercialisation and acceptance of V2G.

6.5.1 The case for action

The preceding sections of this review have identified a range of benefits to V2G that should have the attention of those policymakers responsible for planning and operation of electricity systems and markets, as well as climate change and health. The salient point is that the difference that V2G can make to the adoption of EVs—or perhaps more accurately, the phase-out of fossil fuel-based transport—and to managing the impact of EVs on the electricity system should result in society-wide benefits such as more affordable energy, lower greenhouse gas production and less airborne pollution. Work to improve our ability to quantify the extents of these benefits is a future output of the REVS project.

Transitions relating to sustainability are particularly complex. One reason for this is that there are often many niche innovations providing possible alternatives to the status quo. This differs from transitions in history which usually had one or two alternatives [261]. DER is interesting on this note as it is an umbrella term that includes multiple technologies, including V2G, each with different features and attractions, and which could also work together. As a result, some policy measures are needed to facilitate DER more generally, whereas others need to target V2G. How this transition might play out remains to be seen: the combined potential benefits of DER, including V2G, form the case for change, but once change has occurred V2G would coexist with stationary batteries, virtual power plants, demand response and other technologies to motivate a finite number of interested customers to invest and participate. There could be cumulative benefits for a single customer adopting multiple DERs and customers who are already grid participants may be more receptive to additional means of participating.

6.5.2 Regulatory reform

On this note, there is a natural split in the policy options between market reforms that affect all DER, and non-market regulatory measures that target V2G only. Market reforms facilitate not just V2G, but also other innovations that fit within demand response, grid services and small distributed generators. This corresponds to appliances that can be demand-response enabled, such as water heaters and air conditioners, small batteries and rooftop PV. Market and legislative reforms that allow these technologies to participate in the market through third-party control, reflective pricing and value transfer should also allow V2G to participate [242]. V2G may significantly strengthen the case for these reforms due to the load characteristics of EV charging as both co-incident and unusually flexible.

From the electricity system perspective, a regulatory issue that may require special treatment of V2Gs is the question of how to treat a generator that moves. This is not an immediate concern as V2G is currently conceived to involve a stationary charging point; however, vehicles and charging systems are under constant development, so this could change. Networks therefore need to articulate their requirements for these very new scenarios, and this may require standards and rules to be created or revised. On a similar note, the contribution that V2G and other mobile technologies could make to local system resilience would ideally be recognised in system rules and valued in network planning and decision making.

6.5.3 Funded programs

The most pressing call for government funding of V2G is to enable pilot projects (such as REVS) to demonstrate the technology and provide the information with which to develop sound policy. Pilot projects should not only trial the technology but identify gaps in codes and standards; create new networks of stakeholders; quantify the costs and benefits; and understand the socio-technical dimensions.

Funding will also be required to address the cost premiums that exist between standard EV chargers, smart chargers and V2G-enabled chargers (refer to section 4.1.1, on user challenges, and Appendix A). The argument for incentivising or subsidising the installation of chargers with a greater set of capabilities is partly to increase the potential benefits of V2G but also to stimulate development of the EV and DER industries towards full commercialisation, which should then result in lower costs for the technology. This could take the form of rebates or discounts on approved items or grants to fleet buyers to cover the additional cost of establishing a V2G-enabled fleet. The size of these incentives could be scaled against their wider system benefits, so ‘smarter’ chargers could attract a larger incentive. Similarly, rebates or discounts already available to home battery systems could be extended to combinations of EVs and V2G chargers with scheme rules adjusted accordingly.

6.5.4 Advocacy

As discussed in section 5.2.2, there is very low public awareness of V2G and a lack of knowledge about its impacts. Furthermore, section 4.1.1 raised several questions that potential users of V2G are likely to have about its impact upon different aspects of life and work. This presents an opportunity establish a narrative for V2G that is based in evidence rather than assumptions or rhetoric and look towards normalising energy market participation by end users. Information should be tailored to particular situations and audiences; for example, delivered in partnership with industry to improve point of sale information given to people considering buying an EV or planning their future fleet. Sharing of experiences and illustrative case studies can be more useful than dry facts.

As with many of the market measures, forms of advocacy such as government information campaigns could be equally relevant to the range of services offered by aggregators – not just V2G, but including virtual power plants, home energy management and other similar technologies. Given the existing push to accelerate DER in the electricity market [11], and the overlapping concepts between V2G, virtual power plants and similar technologies, there may be value in educating and raising awareness of the opportunities for people and businesses in DER more generally.

6.5.5 Stakeholder network facilitation

In section 2.2, we described how V2G will create, and is indeed dependent on, new relationships between different stakeholder groups, particularly between the hitherto loosely-connected electricity and transport sectors. Pilot projects are one vehicle for creating these connections. Governments can also help create new networks such as these by facilitating groups and discussions around a common issue such as EVs and V2G. In doing so, government does not necessarily need to take a dominant role [260]. This is certainly the case for the REVS project which is focused on not just trialling technology but engaging many stakeholders in creating and sharing knowledge.

As well as bringing external stakeholders together, governments can create new avenues for their own policy development by creating new networks, or expanding the scope of existing networks, between the separate portfolios of energy, transport, environment and climate change. This can be achieved via the establishment of new working groups for the purpose of policy development.

6.6 Industry

V2G presents a potentially very significant opportunity for a variety of commercial service providers and manufacturers. The journey to realising this opportunity will involve explorations, competitive tensions and new coalitions. Our review revealed a number of recommendations to guide industry actors in this journey.

6.6.1 Collaborate

V2G is a technological niche that needs to develop in order to break through to broader adoption. The extent to which a technological niche is developing successfully can be measured by the quality of learning about the technology and the factors that affect its success, and the quality of institutional embedding of those lessons [262]. Institutional embedding refers to preparations for change: mutual support of complementary technologies (such as DER and EVs), having specific, shared and credible expectations for the technology, and enlisting a broad array of actors in support [262].

In plain language, this means that those engaged in the demonstration and commercialisation of V2G should take a collaborative approach and make lasting changes. Different groups should build industry networks and work together to bring products to market, make connections between V2G and technologies that share its trajectory, such as EVs and DERs, and change their ways of working to support these. Demonstration projects in particular can be instrumental if they engage in open knowledge sharing and collaboration, as is the case for the REVS project which has convened a knowledge sharing group in addition to the core project consortium. Projects such as the V2G Global Roadtrip [2] which digests a large range of international V2G case studies are also very valuable in this way.

A goal of collaboration should be to articulate a collective vision for V2G that includes not just those bringing V2G to market, but also users and third parties such as governments and wider society. Ideally, there will exist a stable, credible, strategic and influential network of industry, users and government, aligned such that resources can be easily mobilised when opportunities arise [262].

6.6.2 Develop business models

While governments and policies have a role to create the right environment for V2G to flourish, it will be up to industry to build products that make V2G real. This requires action throughout the value chain, addressing the needs of both customers (the providers of V2G services) and the varied organisations who may see value from V2G (see 5.3).

Customer facing V2G products must meet several roles:

- Inform customers of the existence of V2G
- Build customer’s comfort in providing grid services from their EV
- Facilitate the pathway between interest and uptake
- Manage customer’s day to day participation and providing value back to them

Based on our research there are several critical factors aggregators could consider in developing V2G products:

- **Uncover customer values:** Customers are diverse and have many drivers for considering V2G such as financial return on investment, energy independence, and backup power (3.1.1). Studies have found that people heavily discount future savings from energy, which suggests that messaging should emphasise value over dollars profit. Tempering this are a number of concerns that customers may have with regard to V2G, such as impacts on range anxiety, freedom, and cost (4.1.1), which will need to be addressed.

- **Integrate many values:** For V2G to thrive, many V2G services will need to be realised simultaneously. Ideally service providers will provide a package that is simple to understand, speaks to both financial and non-financial values, and smoothly co-optimises many services in line with customers’ preferences.

- **Normalise V2G:** Industry should work with lead user groups to explore what is possible and develop use cases for V2G. For example, retailers and aggregators should engage customers in trials to co-create products that address customer concerns, such as any impact to vehicle utility, and respond to customers’ aspirations. The value of such trials will be greater if knowledge is shared with industry, other users and policymakers towards a shared vision for V2G.

For procurers of V2G services, particularly in the energy market, our recommendations are:

- **Open transfer of value:** Open value transfer exchanges (such as Piclo in the UK) have enabled aggregators to build innovative products to provide services into them. These exchanges provide an open means of communicating needs between requestors (networks) and providers (aggregators). Creating this ecosystem requires a concerted effort from requestors to create value. In creating these transfer mechanisms, it will be important to recognise that making V2G into a sustainable economic proposition will require “value stacking”. Accessing one value stream should not prevent access to another.

- **Reduce barriers**: Currently it is hard for new entrants to enter the Australian energy market. This is due to a number of reasons:
    - New entrants lack the **knowledge** and **relationships** required to access value streams

    - The **minimum entry requirements** to participate in the market are high and hard to meet for new entrants
    - **Managing risks** (such as liquidated damages for non-delivery) is challenging for small aggregators
    - **Technical requirements** can add significant cost to each installation and block uptake

  This will require action from regulators and energy market organisations to resolve these barriers. It may include:

    - Providing **additional support** to new entrants to build their understanding of requirements and implications of grid participation
    - Modifying **standards and rules** to reflect the capabilities of distributed resources
    - Ensuring **participation requirements** reflect the capabilities of aggregators to manage risk

- **Embrace dynamic pricing:** Demand response services such as V2G receive value through shifting demand from high to low price periods. These prices should correlate with power system need such as high market prices or network constraint. Dynamic prices are an important means of creating these price differentials. There are a number of ways of creating these prices from simple to more complex:

    - Simple time of use and demand tariffs are commonly available today and provide an initial non-locational dynamic price
    - Bilateral contracts between energy system participants (such as networks) and aggregators can provide simple locational dynamic signals
    - Locational marginal prices provide a real time signal of network need

  In creating these signals it will be important to be aware of the other needs of customers. For example, locational marginal prices may raise issues with certainty (if they are not forecasted) or equity (as they are location dependant by nature).

The aggregator role is not necessarily fixed to one incumbent participant. It could be provided by many energy and transport incumbent or new entrant parties. To enable this, we recommend that:

- Energy market participants recognise many providers of grid services may be new entrants and **may require additional assistance** to provide services.

6.6.3 Develop technical capacity

As discussed throughout the report, V2G requires several key technical pieces to function:

- Hardware, such as chargers and compatible vehicles
- Software, such as orchestration platforms
- Standards, to ensure compatibility of the systems' parts.

In several domains there is significant alignment between V2G and other DER such as solar and demand response. Given Australia's high uptake of DER in a worldwide context, Australia has developed key technologies and capabilities that can be drawn upon to integrate V2G as well as presenting significant opportunities for high IP exports. In other areas Australia will likely be a taker of technology and should focus on importing successful products from elsewhere and driving their costs down.

With these (bi-directional) opportunities in mind, our recommendations for industry are to:

- **Leverage our success with DER integration** on a worldwide stage. Several locally developed DER constraint management algorithms could be easily extended to manage EV grid interaction, and VPP technologies can be readily applied to EVs
- **Standardise interfaces** and **align with other DER standards** as possible to ensure the uptake path for V2G is smooth
- **Modify DER standards** and ensure **smooth validation processes** for V2G grid connection and inverters (even those physically located in the car)
- **Import and validate overseas technologies** such as V2G chargers and capable cars to increase choice in the market
- **Influence worldwide standards** (such as CCS standards) to reflect the Australian context and allow easier adoption locally.

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Appendix A Vehicle and Charger

In many ways EVs are better than ICE vehicles:

- They are more efficient, converting 77-82% of the energy in from the grid to power at the wheel [263]
- They are cheaper to run at around AUD$0.03 per km compared to AUS$0.1 per km for ICE vehicles [264]

V2G adds several elements to this equation. As noted in chapter 4, V2G can impact battery health and requires more complex and costly chargers. This chapter discusses these factors in more detail, with reference to the current research.

A.1 Battery degradation

Commonly prospective EV owners are discouraged by range anxiety, as discussed in 4.1.1. Battery capacity is the most important factor in range [265]. All batteries age due to usage and time. This means that the amount of energy a battery can store or the amount of power it can deliver will be reduced during usage and time, leading to lower capacity and performance. This chapter discusses the key factors in battery degradation: it's causes and strategies to reduce it.

A.1.1 Drivers of battery health

Battery State of Health (SoH) is a measure of battery's overall performance after a certain period compared to its performance when brand new [266]. In other words, battery SoH is a way of understanding how much performance is reduced over time. For instance, if a 40 kWh battery has a SoH of 90%, it would effectively perform similar to a 36 kWh battery. This chapter will use SoH to describe battery degradation.

In most cases, battery degradation is measured by evaluating two primary factors: calendar fade and cycling fade. Calendar fade refers to the degradation caused by storage, whilst cycling fade is caused by the number of charging and discharging cycles of the battery. The most common factors that contribute to battery degradation are shown in Figure 50. The definition of these factors and their impacts on battery degradation are detailed below.

- **Battery temperature** – temperature of the battery strongly affects the rate of degradation. Heat losses due to poorly performing batteries can exacerbate the temperature.
- **Current rate (C-rate)** – is a measure of the rate at which a battery is being charged or discharged compared to its capacity: $C\ rate = {}^{current}/_{rated\ capacity}$. Its units are "C".
- **State of Charge (SoC)/Depth of Discharge (DoD)** – indicates level of charge of a battery, expressed in percentage of its rated capacity.
- **Number of cycles** – is the total number of complete charge/discharge cycles.

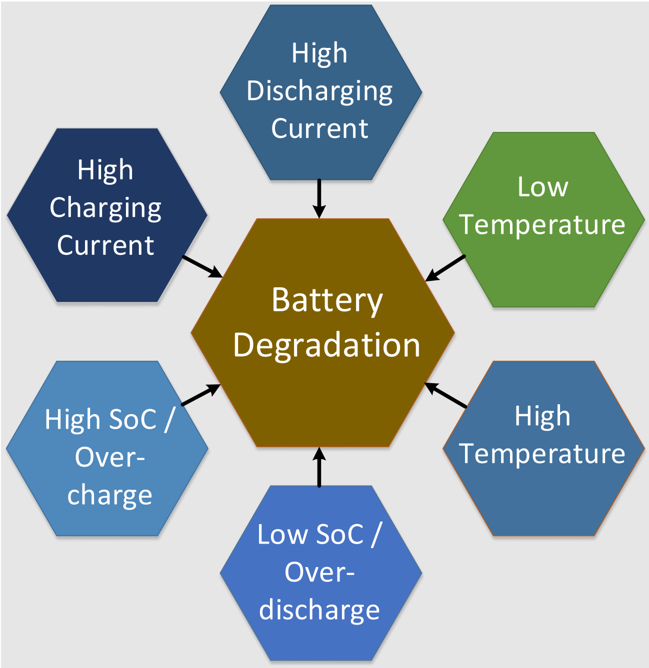


Figure 50: Most common factors that contribute to battery degradation.

Temperature strongly impacts the lifespan of a battery. There are many factors that can influence the battery temperature including ambient temperature, usage, and heating and cooling systems. When parked battery temperature is driven by ambient temperature. As EVs are parked more often than driven it may have a significant impact on the battery life. For example a number of older EVs experienced high battery degradation when owned by people living in hot climates in the US [267].

Temperature is also strongly impacted by battery current when driving or charging. Ouyang et al measured capacity fade at four cycle rates (0.5C, 1C, 2C and 3C) and two ambient temperatures (26oC and 70oC). They showed increasing C-rate increases capacity fade, shown in Figure 51 [268].

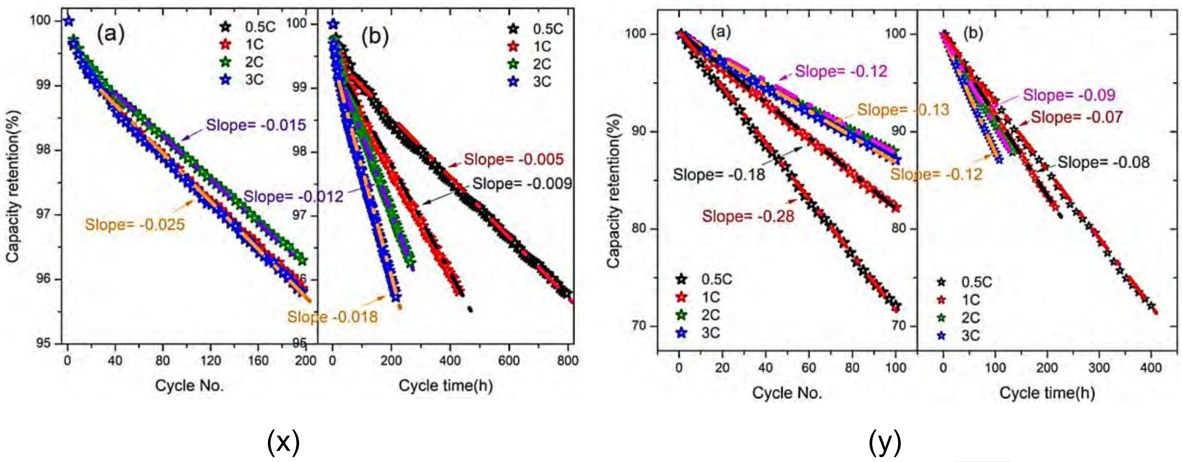


Figure 51: Impact of C-rate and temperature on the capacity fade at (x) 26°C (y) 70°C [268]. Reproduced with permission from the copyright owner.

These results are confirmed by D-I Stroe et. al. They showed that increasing temperature from 25oC to 35oC reduced the battery life by nearly half - from 102 months to 58 months when providing frequency regulation services [269]. M. Schimpe et. al. [270] found that both high and low temperatures will lead to high capacity loss as shown in Figure 52 with the best performance at 25ºC. Similarly [271] showed extreme power fade at - 18ºC, and the best performance at 25ºC.

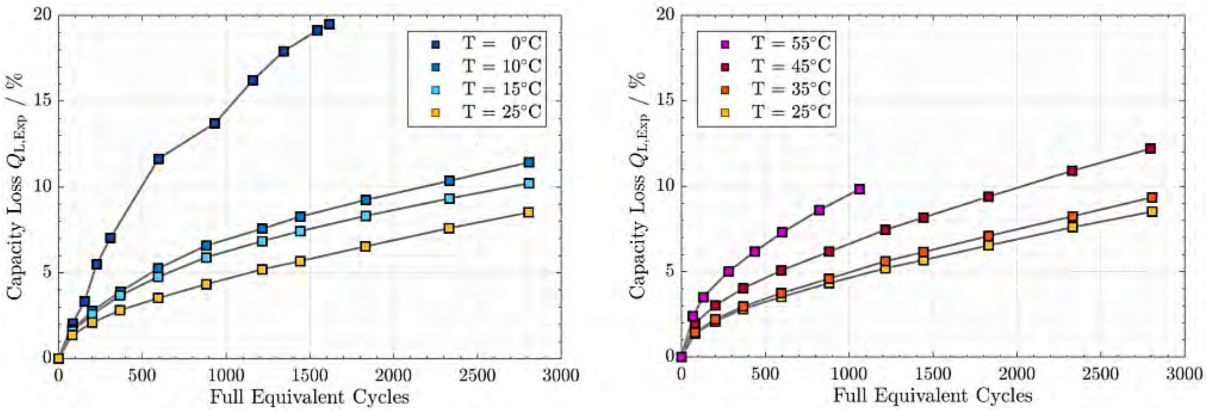
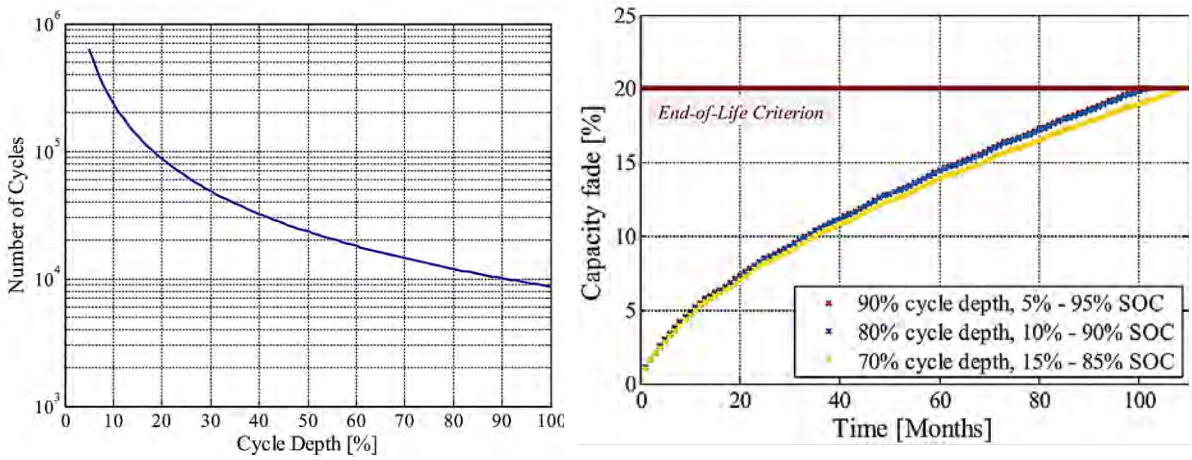


Figure 52: Experimental capacity loss evaluation at various temperatures [270].

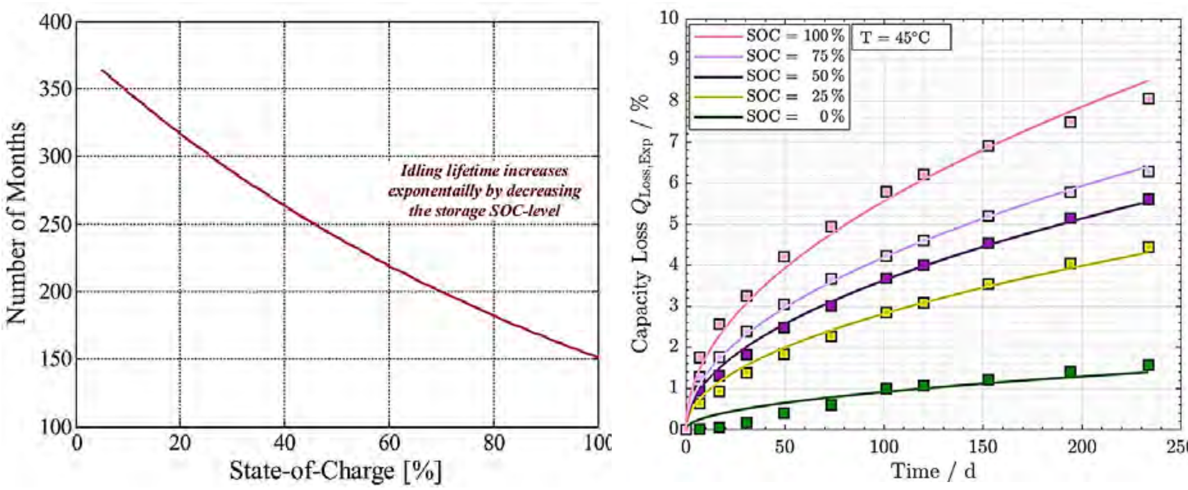
State of charge also impacts battery degradation [269, 270, 272]. Stroe et al. showed that cycling a battery deeply would increase degradation (reduce cycle life) in Lithium iron phosphate (LFP/C) batteries as shown in Figure 53(a) [269]. They also showed that reducing cycle depth to 70% from 90% increases battery life by 8-10 months by when providing frequency regulation services, shown in Figure 53(b) [269].



(a) (b)

Figure 53: Impacts of SoC and DoD on the battery (a) cycling fade (b) capacity fade [269]. Reproduced with permission from the copyright owner.

Storing batteries with a high SoC can also speed up degradation. The authors of [269] showed that storing a battery with high SoC levels speeds up degradation, shown in Figure 54(a). M. Schimpe et. al. [270] also showed this in their study, reproduced in Figure 54(b).



(a) (b)

Figure 54: Battery degradation for various SoC level presented in (a) ref [269] (b) ref [270].

It is clear that battery degradation is greatly influenced by the temperature, C-rates, SoC and DoD levels. The analysis above shows:

- Extreme low or high temperature severely increases battery degradation, while good performance is likely to be achieved at an ambient temperature of around 25°C.
- Increasing C-rates (charging or discharging current) reduces battery cycle life.
- Storing a battery at a high SoC can significantly reduce its life.
- Deeply discharging a battery reduces its cycle life

A.1.2 Impact of smart charging and optimized V2G

Smart charging and optimised V2G allows several strategies to reduce battery degradation:

- Battery pack temperature management
- SoC management

M. Petit et. al. [273] concluded charging in the morning just before a vehicle's first trip significantly improves battery health compared to the charging in the evening. They also found that frequent charging (charge when you can) leads to more battery degradation.

Fast battery degradation occurs at high or low SoC. The authors of [274] showed that keeping SoC in the range of 70% to 90% and charging throughout the night increases battery life by approximately 1.8 years compared to un-optimized charging. Similarly, The authors of [274] suggested that Li-ion batteries that are kept between 30-50% SoC will have longer lifetime. They validated this against the degradation model developed by NREL [274, 275]. Figure 55 presents and optimal battery charge model as proposed by Tan et al. [275] for frequency ancillary services.

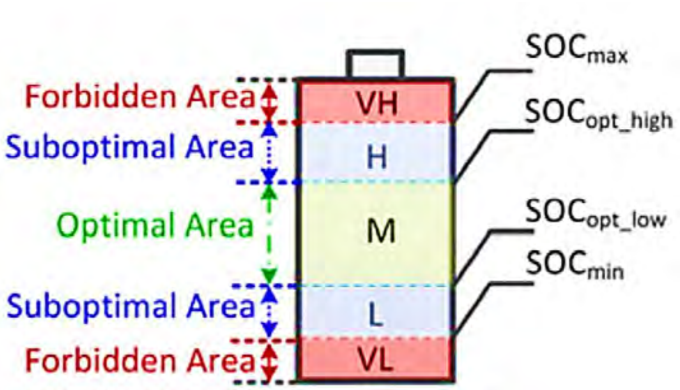
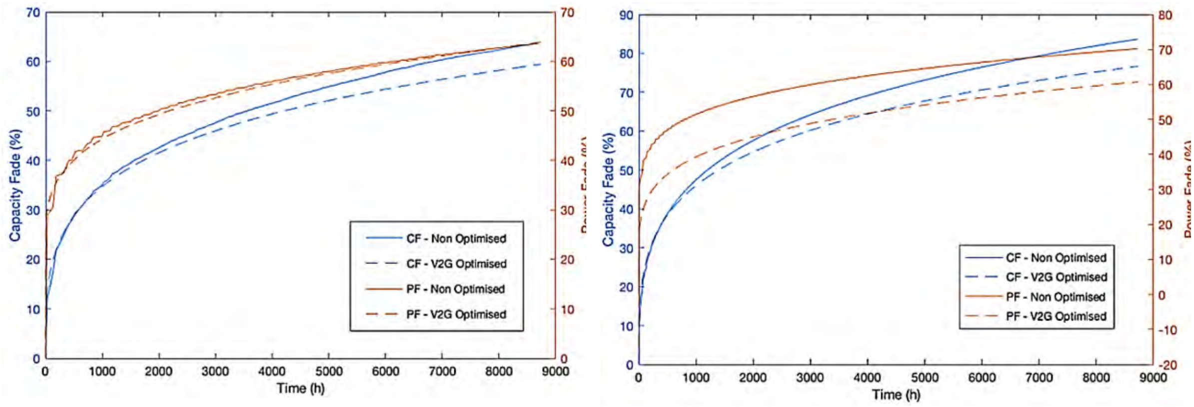


Figure 55: Battery operating SoC to be maintained for minimizing degradation [275]. Reproduced with permission from the copyright owner.

Optimized use of V2G services can maintain the SoC of the battery within the optimal range and extend battery life [276, 277]. The authors of [276] concluded V2G can improve battery SoH by between 6% and 3% over three months by keeping SoC between 38% and 21% and using the 40% - 8% range for V2G services. The key reasons of this improvement are:

- Keeping the battery at its optimal storage SoC
- Keeping the battery within the range where it's internal resistance is lowest to reduce internal heat generation

The authors of [276] showed a significant increase in battery health for optimised charging or V2G, as shown in Figure 56.



(a) (b)

Figure 56: Comparison of capacity loss and power fade for (a) $\Delta SoC_{driving}$ = 7.0% and (b) $\Delta SoC_{driving}$ = 15.0% [276]. Licensed under Creative Commons.

A.2 Chargers

The charger is a key part of enabling V2G. V2G chargers have a fundamentally different design to unidirectional chargers. This section will describe these differences. It will also describe the cost and efficiency of the chargers.

A.2.1 Topology

Unidirectional chargers allow one-way flow of energy from an AC power supply to the EV battery. Figure 57 shows the general topology of a unidirectional charger. Unidirectional chargers rectify the mains power through an uncontrolled rectifier and provide a regulated DC voltage to the charger. Most have other ancilliary blocks such as filters, power factor correction, and isolation for safety and grid compliance reasons. In particular galvanic isolation between the grid and battery is necessary to protect the battery from the charging systems [278]. The control of these types of charger is not complex.

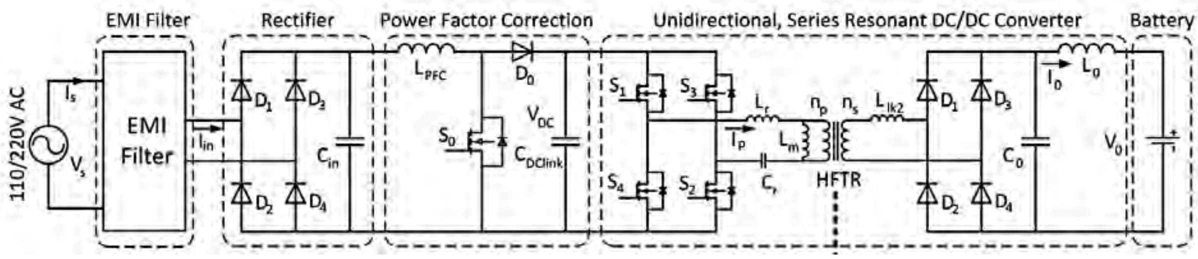


Figure 57: Conventional single-phase unidirectional charger topology [279]. Reproduced with permission from the copyright owner.

Bidirectional chargers are physically different to unidirectional chargers. They require more complex controlled rectifiers to allow power flow in both directions. These controlled rectifiers can act as both rectifiers and inverters. Figure 58 shows a conventional bidirectional charger topology. Because there are far more controlled elements and grid codes for generators (see C.1) control design is more complex for these sorts of chargers.

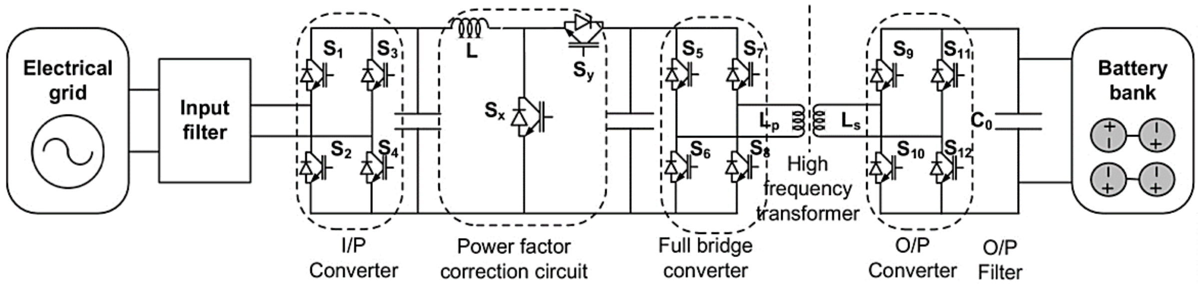


Figure 58: Conventional single-phase bidirectional charger topology [279]. Reproduced with permission from the copyright owner.

Higher power chargers generally use three-phase AC/DC converters as shown in Figure 59. As the power increases further, multiple identical modules can be connected in parallel.

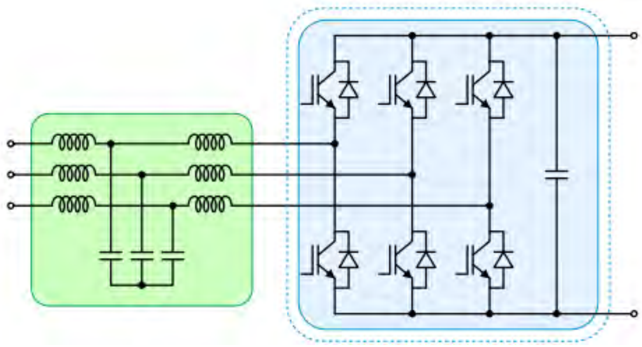


Figure 59: Conventional three-phase AC/DC converter topology [278].

A.2.2 Cost comparison

The cost of a charger mostly depends on the power rating. The higher the power rating the higher the cost, although the relationship between power rating and cost is not linear. Higher power chargers also require additional hardware or safety such as liquid-cooled cables [280]. C Nelder et. al. suggest the key factors driving charger cost are:

- Whether a charger is “smart” or “dumb”
- The number and types of communications systems (Wi-Fi, Ethernet, cellular)
- The number and length of charging cables on a dispenser
- The need for cable retractors and cable management systems
- The type of electricity meter
- The type of authentication and payment system
- Whether a charger is wall-mounted or has a pedestal or pad
- The degree of weatherproofing and durability [280]

Residential chargers are typically much cheaper than commercial. This is because the residential chargers do not require pedestals (as they are mostly wall-mounted) and weatherproofing (installed in a location such as garage), and may only be equipped with a single connector (to match the vehicle’s needs). Similarly, home chargers may not need payment systems and may have a lower level of connection standards. Cost ranges for various types of chargers are shown in Table 20.

Table 20: Cost range for different chargers [280].

Chargers	Lowest cost (US$)	Highest cost (US$)
Level 2 residential	$380 (2.9 kW)	$689 (7.7 kW)
Level 2 commercial	$2,500 (7.7 kW)	$4,900 (16.8 kW)
DC fast charger (50kW)	$20,000	$35,800
DC fast charger (150kW)	$75,600	$100,000
DC fast charger (350kW)	$128,000	$150,000

Charger cost also depends on whether it is equipped with two-way communications capabilities as is required for managed charging. A smart charger can perform two-way communication through a network with the entities who control the charging remotely. More advanced smart chargers require additional standards which also increases the cost. The cost of smart chargers is highly variable. In some cases, it can double the hardware cost. Table 21 summarizes the smart charger cost (networked means the charger is able to communicate).

Table 21: Cost for smart chargers [281].

Chargers level	Type	Cost (US$)
Level 2 residential	Non-networked	1,182
Level 2 commercial	Networked	3,127

Bidirectional chargers allow battery power injection back to grid, thus they must meet the specific grid requirements including discharging infrastructure. They also require extensive safety measures and anti-islanding protection. These increases the complexity and cost of bidirectional chargers.

Although the cost of the charger is relatively high, it will likely fall as the technology matures, demand for charging infrastructure increases, and manufacturers scale-up production. As shown in Figure 60, the cost for non-networked Level 2 chargers has already started declining [280]. The authors of [280] also found that there are significant “soft costs” that need to be reduced. These include costs of permitting delays, utility interconnection requests, compliance with a fragmented framework of regulations, and the reengineering of projects because they were based on incorrect information.

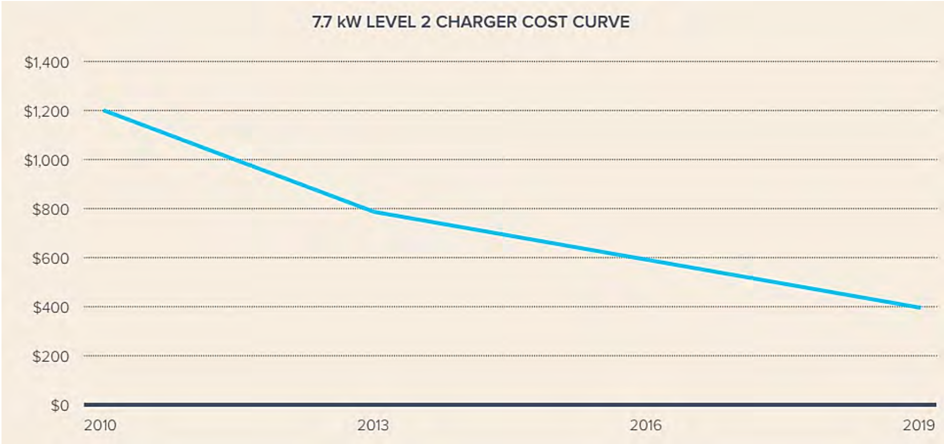


Figure 60: Cost of Level 2 charger over nine years in USD [280].

A.2.3 Energy losses and charger efficiency

Each step in the journey from electricity production to consumption – from transmission wire through to distribution transformer and charge-discharge cycles of batteries – contributes to energy losses. EV charging infrastructure and batteries are no different and also contribute losses. This section quantifies these losses and highlights recent advances in reducing them.

The round-trip efficiency of bi-directional chargers (sending power to and from the grid) is an important technical challenge for realizing V2G services. Round-trip power losses are paid by the EV owners and the aggregators, so impacts the cost of V2G services. This is driving research into better understanding round-trip losses [7]. Power loss occurs across all equipment in the EV supply chain, including the battery itself. Few studies have focused on this topic so far [7, 282-286].

E. Apostolaki-Iosifidou assessed the overall efficiency and losses at each stage if charging and discharging in [284]. Their results are shown in Table 22. The transformer and PEC are the largest contributor to losses. Transformer losses can be minimised by operating the transformer close to its rated power [7, 284]. Additionally, transformer losses may not affect the revenue made by the EV owner as they are commonly not 'behind the meter' [7]. PEC losses increase with more demand. Similarly charging loss is lower than discharging.

Table 22: Measured power loss at various component of EVs charging

Component	Ac current (A)	Percentage loss	
		Charging	Discharging
EV battery	10	0.64	0.64
	40	1.69	1.91
EV PEC	10	6.28	16.67
	40	5.77	19.23
EVSE	10	0.10	1.42
	40	0.29	1.39
Breakers	10	0.00	2.80
	40	1.30	0.60
Transformer	10	10.20	14.60
	40	3.33	6.65
Total	10	17.22	36.13
	40	12.38	29.18

The Parker project also measured charger efficiency [161, 287]. Figure 61 presents the charger efficiency calculation they used, and Figure 62 shows their results. Generally, more charge/discharge power increases efficiency, peaking at around 90% at rated power.

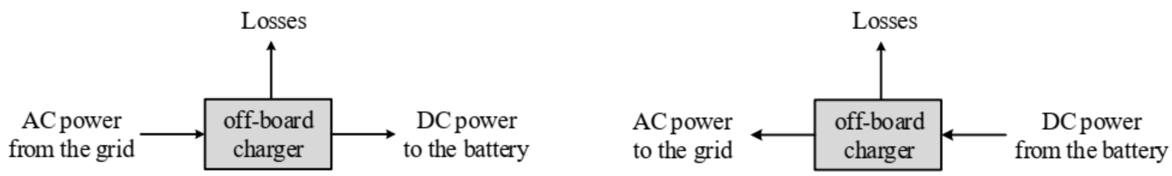


Figure 61: Methodology of charger efficiency calculation under parker project [287]. Reproduced with permission from the copyright owner.

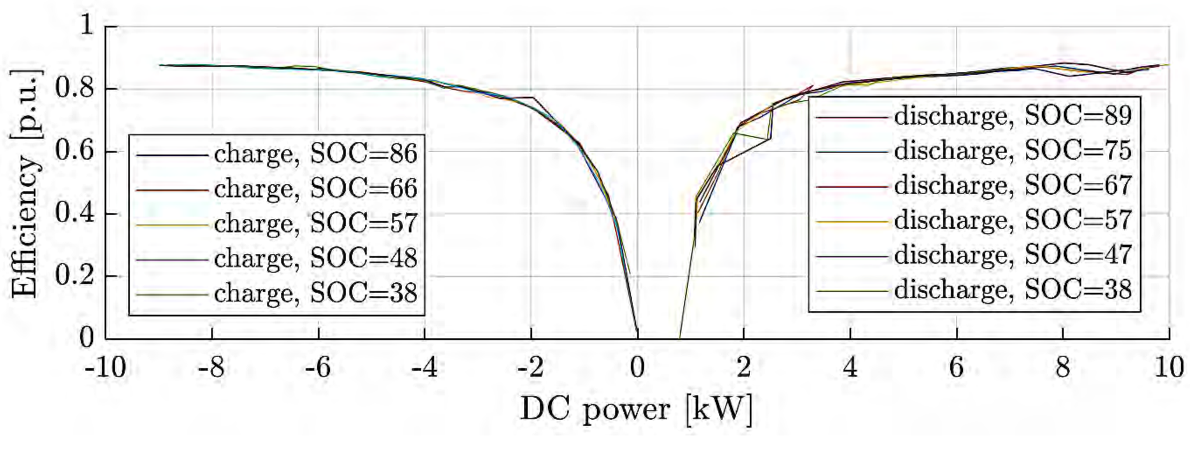


Figure 62: Efficiency map at various DC power set point [287]. Reproduced with permission from the copyright owner.

Clearly increasing efficiency of the PEC will increase the value proposition for V2G. Multiple studies have focussed on this [140, 285, 288-290]. Some studies have investigated soft-switching technology as a means to increase efficiency [140, 285, 290, 291]. Soft switching requires the transistors in the PEC on off at zero-current or zero-voltage. Liu et al. designed a new bidirectional soft switching technology charger using and silicon carbide (SiC) based MOSFETs in [291]. The laboratory prototype showed an overall efficiency of 96%. With the

AC/DC stage being 98.5% efficient. Similarly, the authors of [140] achieved an efficiency of 96.80% for their soft-switching bidirectional converter.

Future research may also focus on different materials for switching devices. For instance, utilizing Gallium Nitride (GaN) based switches instead of SiC or Si based switches could increase the efficiency [289, 292] by increasing the switching frequency.

There are several companies around the world manufacturing different types of EV chargers. A detailed report on efficiency of these commercial chargers is not available openly. However, some companies have mentioned the charger efficiency in their manual without any details of measurement methodology. Table 23 lists the efficiency and other technical parameters of selected commercially available chargers. As can be seen, efficiency is high for chargers with high ratings and in most of the cases it is equal or greater than 95.0%. The Tritium Veefil high power DC fast charger (rated up to 350 kW) attains 98.5% efficiency.

Table 23: Reported efficiency of commercially available chargers

Company	Charger model	Charger type	Rated power (kW)	Power Factor	Efficiency (%)	Supported connector types
ChargePoint Inc. California	Express 250	DC fast charge	62.5 kW	0.99	>95.0%	CHAdeMO, CCS1 (SAE J1772™ Combo), CCS2 (IEC 61851-23)
	Express 200 DC	DC fast charge	50.0 kW	0.99	>92.0%	CHAdeMO, CCS1 (SAE J1772™ Combo)
	Express 100 DC		24.0 kW	0.93	>94.0%	CHAdeMO, CCS1 (SAE J1772™ Combo)
EVBox, Netherlands	Troniq 50	DC and AC	50 kW DC and 22 kW AC	>0.99	95.0%	CHAdeMO, CCS2, IEC62196 Level 2
	Troniq 100	DC and AC	100 kW DC and 22 kW AC	>0.99	95.0%	CHAdeMO, CCS2, IEC62196 Level 2
	Ultroniq Ultra-fast charge	DC fast charge	175 kW	>0.98	95.0%	CHAdeMO, CCS2
EFACEC, Portugal	HV 175	DC fast charge	161 kW	0.98	>95.0%	CHAdeMO, CCS/Combo-2
	QC45	DC and AC	50 kW	0.98	>93.0%	CHAdeMO, CCS/Combo-2, IEC62196 Type-2
Tritium PTY Ltd, Australia	Veefil 50kW	DC fast charge	50 kW	0.99	>92%	CHadeMO and CCS (Level 1 or 2)
	Veefil high power	DC fast charge	up to 350 kW	0.99	98.5%	CCS Level 1, CCS Level 2 & CHAdeMO

Appendix B Aggregator business models

As described in 5.2.2, aggregators perform a critical role in the V2G value chain. Their core function is to manage risk, both on behalf of the energy system and end use customers. For example, aggregators manage delivery risk for the energy system, and manage uncertainty and risk around energy system service needs on behalf of the customer. This is shown in Figure 63.

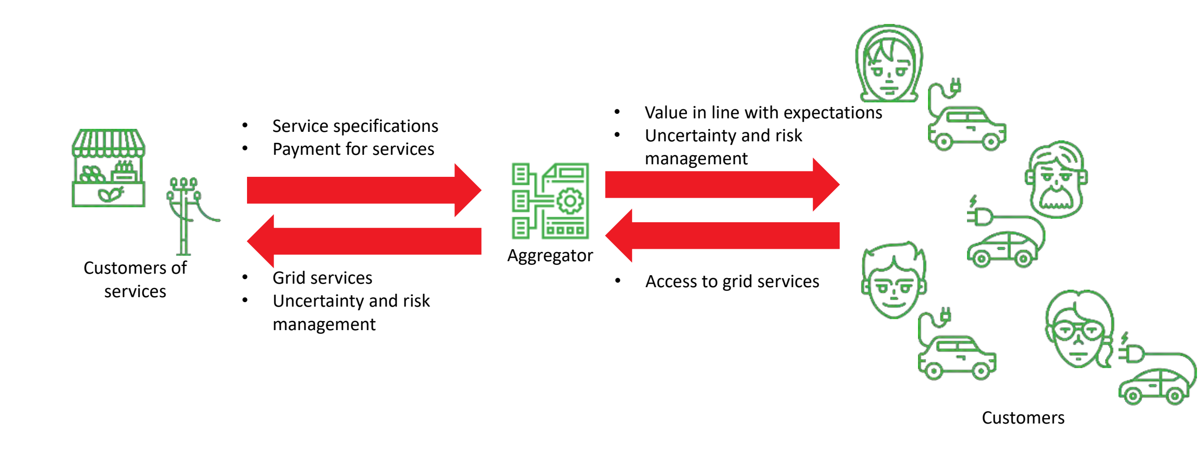


Figure 63 Role of aggregator

B.1 Aggregator types

As described in 5.2.2 there are several possible business models for aggregators, shown in Table 24. These are described in more detail subsequently.

Table 24 Potential aggregator business models [241]

Model	Explanation	Example
Combined aggregator – retailer	A retailer acts as an aggregator	Octopus Powerloop (Octopus Energy)
Combined aggregator – market participant	An aggregator who is a market participant, separate to the customer's retailer. There are two participants per connection point (retailer, aggregator)	JuicePlan (Enel-X)
Combined aggregator – DSO / Distribution network	Distribution network acts as aggregator. This arrangement would not comply with ring fencing rules in Australia and hence would not be allowed, however is acceptable for trials.	Electric Nation (Western Power Distribution)
Independent service provider	Aggregator is a service provider for another market actor	SwitchDin (Load control)
Independent aggregator	Aggregator sells services to another market participant (e.g. retailer)	Reposit Power (Distributed storage)

Model	Explanation	Example
Customer as aggregator	Customer acts as their own aggregator. Likely only possible for large customers	University of Queensland (Virtual hedge using centralised battery)

B.1.1 Combined aggregator-retailer

This model is the least complex. Retailers already hedge customers against energy price volatility therefore may be well-placed to provide a similar demand response service [177]. All customers[5] already have an energy relationship with a retailer. This model is already in use in some places. Two examples of this are Octopus' Powerloop and Ovo's Project Sciurus [118]. Similarly, there are products in the US where integration between distribution networks and retailers are common. Some examples of these are Austin Energy's EV360 project [113] and Green Mountain Power's Virtual Peaker [293] initiative.

In these projects it is common for the value of the services to be presented as part of the customer's energy bills as a rebate, a bill credit, or feed in tariff. Free charging hardware is also common as part of trials.

There are no regulatory barriers to this business model in Australia.

B.1.2 Combined aggregator-market participant

In some jurisdictions it is possible for aggregators to act in the market separately to retailers. In California's electricity market DER and demand response can participate in markets providing energy and ancillary services. This has led to several organisations providing various sorts of EV demand response services into this market.

One example of this is the BMW ChargeForward project [70]. In this project BMW (in collaboration with PG&E) provided day ahead and real time energy from a combination of orchestrated EV charging and a second use battery. Customers were paid incentives based on how often they participated in events.

The Enel-X JuicePlan [37] and JuicePoints [294] products create a resource of managed charging for Enel-X to offer into demand response markets such as California's. In these products customers either get a lower subscription feed (JuicePlan) or financial rewards (JuicePoints) for participation.

In Australia, this model is possible only for frequency control ancillary services. Customers may appoint a market ancillary services provider (MASP) to trade ancillary services in addition to their energy retailer [295]. The current two-sided market consultation being undertaken by the Energy Security Board aims to expand demand side participation in the market beyond this [231].

B.1.3 Combined aggregator – DSO / Distribution network

In this model a distribution network acts as an aggregator. In jurisdictions with separate distribution networks and energy retailers this model is unlikely to be suitable. A review report of the EU market stated *"regulated and unregulated roles should not be combined"* [241].

[5] Except for some large customers who may participate in the market directly

Similarly, in Australia ring fencing rules require networks to separate monopoly from contestable (competitive) business activities [296]. This model is however commonly used during trials as it allows networks greater flexibility to test various models.

An example of this is the Electric Nation project undertaken by Western Power Distribution [108]. This project tested managed EV charging as a means of mitigating congestion in the distribution network. While the project was a success Western Power Distribution's EV strategy states that they *"expect that smart charging solution such as those demonstrated in electric nation will be the domain of electro-mobility service providers"* [139].

Distribution networks however have one of the largest drivers to manage EV charging. A UK study showed that across Britain 32% of LV feeders will require intervention when 40-70% of customers have EV charging, based on 3.5kW chargers [297]. Distributors have a role to provide clear signals to aggregators and retailers of the response requirements. Western Power Distribution have approached this by providing time of use price signals and calling for dynamic response in areas that are more highly constrained through their "flexible power" platform [139].

In Australia distribution networks are not permitted to participate in the market. They may undertake these activities only through ring-fenced subsidiaries. However, some distribution networks are running trials for EV services such as Energy Queensland's "EV SmartCharge" program [138].

B.1.4 Independent service provider

Independent service providers provide the tools used to procure services from EVs but not the services themselves. This organisation may be a hardware or software manufacturer. An example of this sort of organisation is Kaluza, which is providing the hardware and software for OVO's Project Sciurus [118].

In Australia there are several service providers who offer similar services in the demand response or PV/home battery market. An example is SwitcheDin [298] who offer a "white label" demand response platform.

There are no barriers to this sort of business model in Australia. Success with this model relies on agreements with other market participants such as networks or energy retailers.

B.1.5 Independent aggregator

In this model an aggregator sells services to other market participants such as retailers or networks. This model has been adopted in the distributed storage market by some providers in Australia. An example of this is Reposit Power [299]. Reposit batteries are used by 11 partner networks and retailers for services. Some retailers offer "bring your own battery" plans with Reposit hardware. An example is Powershop who offer Reposit customers between $20 and $236/year for activation of their Reposit battery in the "Grid Impact" virtual power plant [106].

This model is currently active in Australia. As for "independent service provider" success will rely on the ease of procuring service agreements with other market participants. A key feature of this mode is that the aggregator may sell services to several participants simultaneously (e.g. to a retailer and a network).

B.1.6 Customer as an aggregator

Larger customers may choose to participate in markets themselves. This would be especially true for customers with significant numbers of chargers and who may already be market price exposed for energy purchases. For EV charging this model is not yet demonstrated however it has been used with centralised batteries. The University of Queensland have used a 1.1MW/2.15MWh battery as a virtual hedge to reduce their energy costs and contracting requirements [74].

As fleets increase in size this model is likely more credible for locations with large numbers of EVs charging simultaneously. This may for example be bus depots or warehouses with delivery trucks.

This model is available in Australia however will require higher EV uptake to succeed.

B.2 Who may act as an aggregator?

Section 1.1.2 has described how aggregation services could be bundled with other energy services or offered as a standalone service. All of these services needn't be provided by existing energy market organisations. Non-energy organisations may see services such as these as a diversification opportunity. Diversification is not without risk. The most likely parties to diversify into this space are ones that are "adjacent", or ones that already provide services in a similar domain. Bain and Company presented six ways a company may grow into adjacent space, as shown in Table 2 [300].

Table 2 Types of adjacency

Type of adjacency	Example
Product	Selling a new product or service to existing customers. For example a car manufacturer who sells internal combustion engine vehicles selling electric vehicles
Geographic	Expanding into new geographical market. For example an established overseas vehicle grid services operator selling their core product in Australia
Value chain	Moving up or down the value chain to a new set of activities For example a charging optimisation software provider becoming an aggregator
Channel	Selling an existing product through a different channel For example a charger manufacturer selling their chargers at hardware stores
Customer	Selling an existing product to a new customer segment For example a commercial focussed charging platform provider selling services to residential customers
New business	Building a new business around core capability (essentially repurposing strong core capabilities) For example an organisation that has strong optimisation capabilities in another industry

An article in the Harvard Business Review discussed adjacency moves of several large organisations [301] and concluded successful adjacency moves had a disciplined approach and only attempted moves in one dimension at a time. For example, expanding the same product into a new geographic region or selling an adjacent product in the same geographical region, but not both at once[5].

The most likely organisations to begin offering VGI services are those that already offer adjacent services. This obviously includes many Australian energy system players such as retailers, who are already moving into this space. There are several other adjacent organisations who are not currently providing these services in Australia who may provide V2G services, as shown in Table 3.

Table 3 Examples of adjacent organisations

Type of organisation	Examples
Retailers	AGL, PowerShop, Origin
Vehicle demand response providers (non-Australian)	Octopus, Ovo, Nuvve, ev.energy
Providers of other sorts of demand response	Reposit Power, Enel-X, Sonnen
Charge infrastructure providers	JET charge, ChargePoint
Fleet management and vehicle leasing companies	SGFleet, LeasePlan
Vehicle manufacturers	Nissan, BMW
Fuel or fuel card providers	BP
Telecommunications companies	Telstra

There are several reasons an organisation may begin offering adjacent services. For example, a vehicle manufacturer may offer V2G services as it is a unique capability of their vehicles and assists sales of their core product. Similarly, an energy retailer already aggregates energy risk and has an existing relationship with their customers. V2G is both an energy price hedge and a value-add service to their customers. Business drivers are complex and unique to individual organisations. This report does not aim to discuss these in detail. Individual organisations will have better visibility of their unique circumstances and drivers.

Customers have diverse values and expectations from their electric vehicles and grid services, as is discussed elsewhere in this report. Fleet buyers will have different sets of values, expectations and responsibilities in decision making as compared to private buyers, and may involve multiple stakeholders with different priorities, such as fleet, facility, energy and sustainability managers. Aggregators, car dealerships, hardware installers and other customer-facing entities need to package their offering in a way that is appealing to the customer.

B.3 Aggregation value propositions to customers

Table 25 summarises a range of recent grid services offers, including trials, focusing on the claimed benefits to customers. The most prominent emphases were bill savings, convenience and increased self-reliance through the better use of a customer's existing solar and battery. Offers emphasising bill savings generally put a number to those savings, either through an estimated monthly bill saving or fixed cashback amount. Convenience was expressed either through the inclusion of an app, which would provide easy monitoring and control capabilities, or reassurance that the installation and operation would not be overly complex. The two Australian examples emphasised self-reliance with assumption that the customer already owned or intended to purchase a solar power system and/or a battery.

Table 25: Summary of grid services offers.

Service provider and product	Customer offer	Emphasis
Octopus Energy (UK) Powerloop (trial)	Two year lease vehicle contract with charger, app, 100% renewable energy, smart meter and cashback bundled in [171].	Savings
Enel-X (USA) JuicePlan	Charger, app and dashboard supply and install, emphasising convenience. No upfront cost and fixed monthly subscription [37].	Convenience
Western Power Distribution (UK) Electric Nation (trial)	Cash rewards, free charger for the duration of the trial and possibility of purchasing charger at low cost at trial end. Promoted the broader aims of the trial ahead of participant benefits [108].	Participation Savings
Reposit Power (Aus)	Cheaper power through smart management, home automation, app and data visibility, earn income [299].	Self-reliance Convenience
Tesla (Aus) Tesla Energy Plan (trial)	Discounted battery, bill savings, use more of own solar power, resilience from blackouts, app	Savings Self-reliance

Appendix C Standards

C.1 Grid connection standards

The V2G charger system must as a whole comply with several grid-related standards. Primarily it is an inverter therefore it must comply with the grid-connected inverter standards, specifically [302]. As these standards are unique to Australia and New Zealand imported inverters will need to be validated against them.

AS4777 defines several requirements for inverters, specifically around the system conditions under which the inverter must remain connected or trip. AS4777 contains requirements around:

- Electrical safety including Wiring rules, installation requirements, and connectors
- Power quality including Power factor, Harmonics, Flicker, transient voltages, DC current injection, and current balance
- Voltage support including power factor, volt-var, and volt-watt
- Demand response modes from AS4755
- Anti-islanding requirements (both active and passive)
- Withstand of grid conditions

Each of these requirements exist to control a specific set of risks.

Electrical safety rules are common for all electrical equipment. They are concerned with ensuring there is a low risk of shock or injury to people or damage to equipment from the device. For V2G chargers this will also include consideration of the relevant charger and connector standards (discussed in 5.1.4).

Power quality rules ensure that the properties of the electricity remain adequate. This includes continuous operation issues such as harmonics, dc currents and balance and issues caused by change in power output or connection such as flicker, and transient voltages.

Voltage support rules ensure that the voltage at the inverter's connection point remains acceptable and within bounds. More recent standards have focussed on inverters forming an active part of voltage control and define multiple control modes, which may be used in isolation or combined. These include:

- **Power factor** mode which operates the inverter at a fixed power factor
- **Volt-Var** mode which alters the reactive power setopoint of the inverter with grid voltage (usually inductive at high voltages and capacitive at low voltages)
- **Volt-Watt** mode which alters the active power output of the inverter with grid voltage. Usually reducing generation or increasing demand at high voltages and the inverse at low voltage.

Most distribution networks require one or more of these modes active from all embedded generation. For example, EVOenergy requires volt-var or volt-wall response modes from embedded generation connected to their network

AS/NZS 4777 requires inverters have demand response capability that complies with AS/NZS 4755. It defines several modes of demand response capability as defined in Table 26.

Table 26 Demand response modes in AS/NZS 4777 [302].

Mode	Requirement
DRM 0	Operate the disconnection device
DRM 1	Do not consume power
DRM 2	Do not consume more than 50% of rated power
DRM 3	Do not consume more than 75% of rated power and source reactive power if possible
DRM 4	Increase power consumption
DRM 5	Do not generate power
DRM 6	Do not generate more than 50% of rated power
DRM 7	Do not generate more than 50% of rated power and sink reactive power if capable
DRM 8	Increase power generation

Only mode 0 is compulsory. This standard requires a physical connection on the inverter, which is rate in international standards. For some inverters this requires physical modifications to enable compliance.

Anti-islanding requirements ensure that inverters don't form islanded networks. This is where the inverter (possibly with other equipment) unintentionally supplies a section of network that is not connected back to the main grid. This is a safety issue and can be dangerous to utility workers who may not expect the network to be energised. Similarly, it is unlikely the quality of supply will meet the appropriate standards. Inverters can intentionally island in certain conditions but that requires the correct equipment, controls, and isolation be installed. Anti-islanding controls can be active or passive. Passive controls detect island conditions through system conditions. Active controls actively perturb the inverter output and measure system response to detect an island condition.

Inverters must remain connected for likely system normal or grid transient conditions. Historically inverters were not required to remain connected during faults as a means of ensuring islands are not formed. As the grid increasingly relies on distributed inverters for grid stability remaining connected for grid disturbances is more important. This requires more careful consideration of the interaction between withstand and islanding requirements.

The REVS project will validate a V2G charger against this standard. Specific learnings will be shared as part of future milestones.

For market participation the system must also comply with market standards, such as the Market for Ancillary Services (MASS) specification for frequency control services [303]. These standards contain requirements for metering, provision, and validation of market services. The MASS's main relevant requirements are controls and metering.

Providing frequency control services requires frequency responsive controls. The MASS is not prescriptive about the topology of the control and defines two types of control: variable and switching controllers. Controllers can also provide a combination of both types.

Variable controllers *"must operate so that a variable amount of market ancillary service commensurate with the difference between Local Frequency and the Variable Controller's Frequency Deadband"* [303].

Switching controllers change their output in one or more steps as frequency changes through their set points.

The amount of FCAS delivery depends on the response of the controller to the frequency disturbance and is defined by the basic formula:

$$FCAS = \frac{2}{t_e - t_s} \int_{t_s}^{t_e} p(t)dt$$

Where t_s and t_e are the start and end times for the frequency bands (0-6s, 6-60s, 60s-5m) and p(t) is the power output of the device. Delivery is also the minimum of the band and the next time band (e.g. for fast raise it is the minimum of the 0-6 and 6-60s response).

Metering of FCAS delivery requires high-speed monitoring (particularly for contingency FCAS services). In particular, it requires frequency and power measured at a 50ms interval or less. AEMO is relaxing these requirements for some trials, such as the VPP demonstrations project currently underway [304].

Appendix D Control Approaches and Data Management and Privacy

D.1 Control approaches

EV charging is inherently uncertain. Cars plug in or unplug at any time, move between chargers, and arrive with an unknown state of charge. Aggregators must manage this uncertainty to participate in the market. The often must bid in the electricity market a day (or at least an hour) in advance. Because each vehicle's capacity is so uncertain it is very challenging to accurately predict bidding capacity.

Several studies have focused on developing control algorithms that can deal with this uncertainty [235, 305, 306]. Probabilistic approaches can manage EV uncertainty. In this approach uncertain parameters are modelled by probability distribution functions and are dealt with different probabilistic strategies such as Monte Carlo simulation, scenario based analysis, etc. The study in [306] proposed a method to compute day ahead probabilistic charging loads using the combined SoC of large number of EV units. Their proposed strategy not only accurately predicted the day ahead charging loads, it also reduced the computational loads significantly. Vandael et al. used reinforcement learning method to reduce the error in day-ahead forecasting of EV loads and minimize the overall operation cost of energy imbalance [305].

Zhan et. al. proposes an aggregate model for a fleet of V2G capable vehicles that aims to reduce the difficulty of forecasting V2G capacity based on individual EV [307]. Figure 64 shows the average reserve power profile for 5,000 private EVs (battery capacity of 24 kWh) calculated by the method in [307]. Both hourly and day ahead values closely follow the real time values.

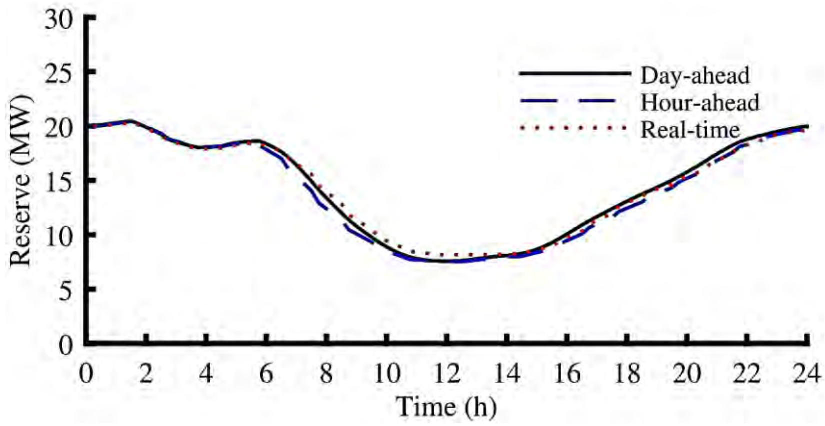


Figure 64: Average reserve power profile for 5000 private EVs [307]. Reproduced with permission from the copyright owner.

Many of the studies in the literature focus static algorithms that are repeated with updated information as it arrives [235, 308]. For instance, the authors of [235] proposed a three-step algorithm (aggregation, optimization and real time control) that are executed iteratively to adapt to a dynamic environment. Gan et al. defined an optimal control problem in [308] for EV charging schedule and then used a decentralized algorithm to iteratively solve the problem. The EVs update the charging profiles in every time-step according to the control signals. Instead of updating information in every iteration, Liu et al. proposed an event-driven approach where charge sequences were recalculated only if any events (one or more EVs are plugged-in or plugged-out before their nominated period) was occurred [309].

Another alternative method that has been developed to cope with the EV dynamics is online based control which uses some prediction but mostly relies on currently available information [310-313]. Most off-line algorithms assume that uncertain parameters are either known beforehand or forecasted. This is somewhat unrealistic and prone to forecast error. Consequently, online based control algorithms are much more robust in comparison. [310] presented an online multi-dimensional auction mechanism where the agents bid for power and also state the availability of vehicles for charging. The authors of [313] proposed an online coordinated charging schedule algorithm that aims to minimize the energy cost while fulfilling the charging demand within deadline. This discrete time model was driven by car plug in and out events. Consequently, this model generates schedules flexibly unlike conventional time slotted models. Figure 65 shows average charge rate for light, moderate and heavy traffic scenarios for five algorithms [313]. The algorithms are (1) optimal – off-line based charging with all future information known, (2) ORCHARD – proposed in [313], (3) online algorithm (OA) – conventional online algorithm, (4) online average charging (AVG) – charging demand is evenly distributed during peak, and (5) online eagerly charging (EG) – EV i is charged with maximum charging rate. The ORCHARD model proposed by the authors shows the best performance overall.

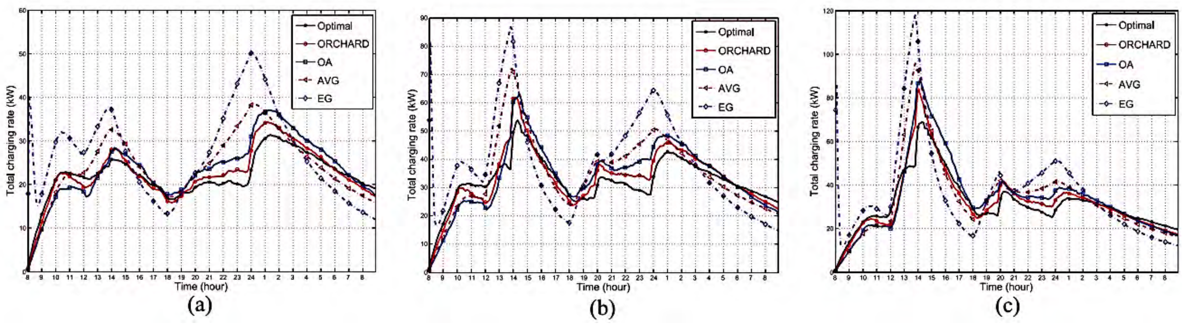


Figure 65: Charging rate comparisons of five algorithms for (a) light (b) moderate and (c) heavy traffic [313]. Reproduced with permission from the copyright owner.

The development of further improved robust algorithms that manage uncertainties as well as battery degradation, energy efficiency, and overall economic benefits is an ongoing area of active research. It is also essential that these efforts are directed at transitioning these algorithms from theoretical demonstrations into real-world implementations.

D.2 Data management

V2G and grid services requires data to be transferred between several entities such as grid operators, aggregators, and control systems [314]. Aggregators collect various types of data in different time domains from millisecond to minutes to hours. The International Energy Authority states there were more than 5 million EVs on the road by the end of 2019 worldwide, expected to exceed 23 million by 2030 [246]. Co-ordinating, transmitting and storing data generated by these millions of EVs will be a big challenge.

D.3 Data privacy and security

Privacy and security of EV data will be very important for all parts of the EV/V2G value chain. EV data can be used to determine personal information about drivers including driving pattern, current location, payment, and their activities. The data makes it possible to pinpoint the location of a specific person or a group when they are travelling. This data is required for smooth operation of V2G, however customers value their privacy highly. [315]. Therefore, V2G networks must incorporate centralised security architecture, which improves privacy and security, mutual authentication, verification and e-trading access [314].

Appendix E Current Australian market value streams

The most common value streams in worldwide V2G projects are:

- Energy market arbitrage
- Ancillary services
- Network congestion management

This chapter presents a summary of the current energy market in Australia and the value that might be achieved. This spans services currently traded on a market (energy and some ancillary services) and network congestion management.

The numbers presented in this section should be considered as a guide only. The energy market is dynamic with a constantly changing mix of generation and load. While some value streams are lucrative based on current market conditions as more service providers enter the market the financial outcomes may change significantly.

E.1 Energy market

Electric vehicles, much like any form of storage, realise energy market through arbitrage. That is buying energy at low cost times and selling it at higher cost times. The amount of revenue available depends on how much this energy price varies. In recent years, the generation mix in the Australian energy system has changed. Increasing numbers of inflexible generators such as wind and PV together with the closure of traditional generation has increased the variability in price. Figure 66 shows how variability in energy price has increased since 2009 in Queensland.

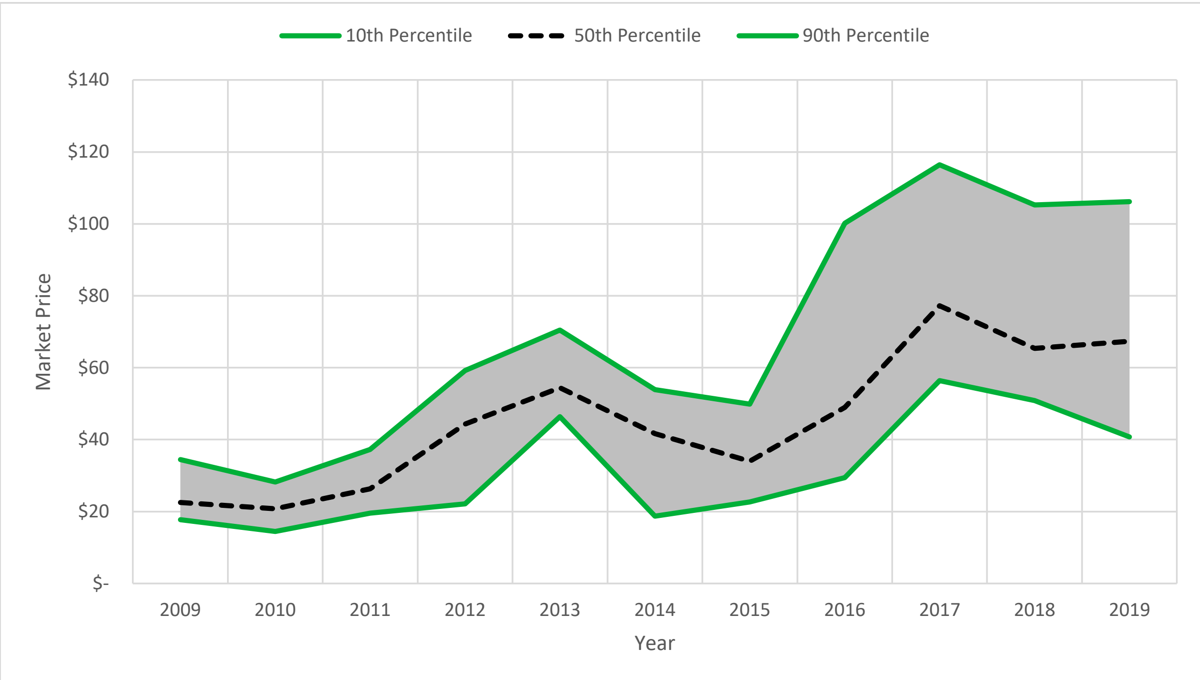


Figure 66: 10-90th percentile energy price range 2009-2019 (QLD)

In Queensland much of the generation increase has been driven by PV. While the “duck curve” impact on demand has become well known there is a similar impact on price. Figure 67 shows the Queensland energy price variability over a day. The impact of solar PV can clearly be seen around midday.

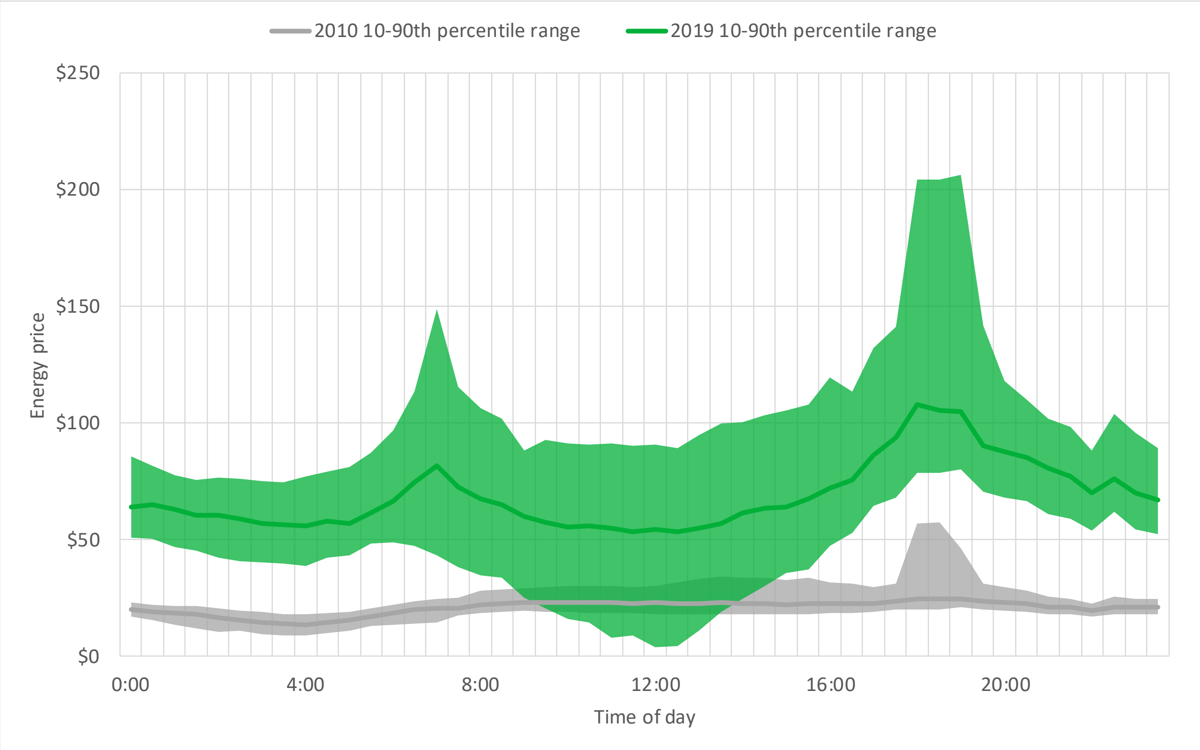


Figure 67: Duck curve: change in average daily energy price 2010-2019 (QLD)

Unlike a stationary batteries EVs are not plugged in all the time. To maximise benefit from V2G, EVs must be plugged in both when prices are at their highest and lowest. For example, in Queensland this would require EVs to be plugged in at midday and around 6PM. To illustrate this Figure 68 shows how much value there is to be transacted if 1MWh is shifted from the lowest to the highest price periods for different plug in times. Clearly to maximise value customers should be encouraged to plug in as early and for as long as possible.

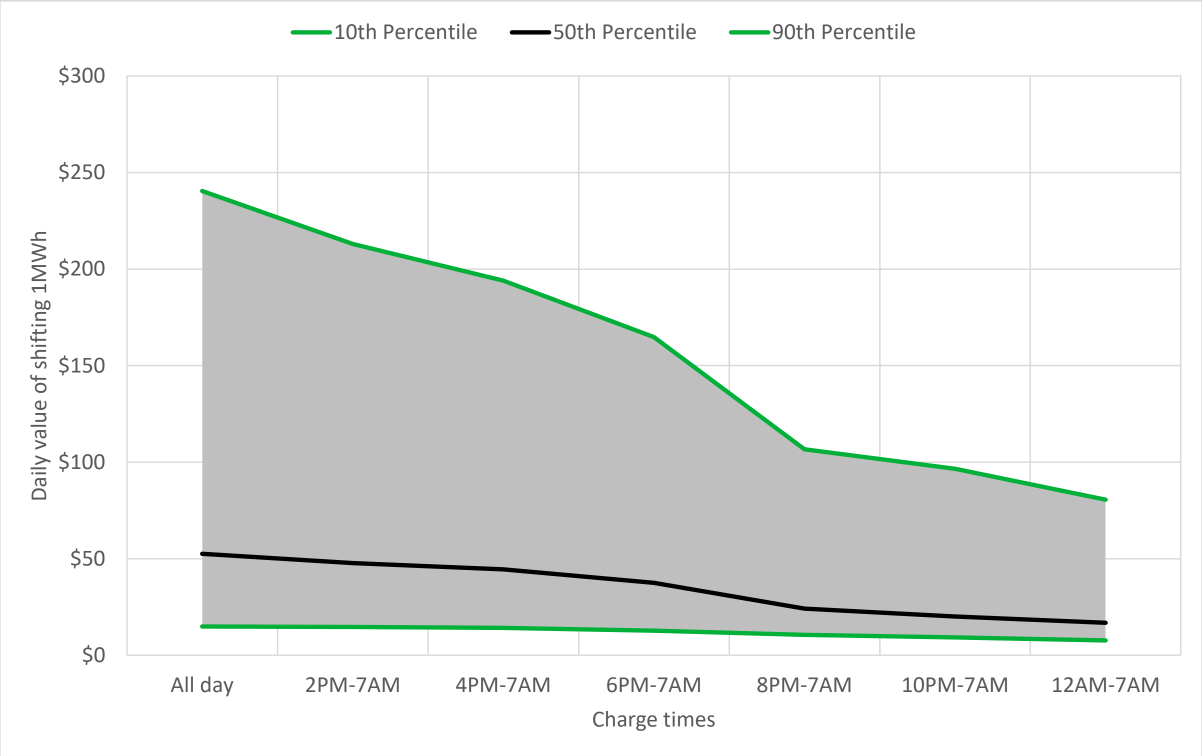


Figure 68: Plug in time impacts on value 2009-2020 (QLD)

Not only is plug in time important, large amounts of the value are dependent on a few critical days each year. This can be seen in Figure 69. Over a third of the total value (in energy price) is dependent on the top five days in an average year.

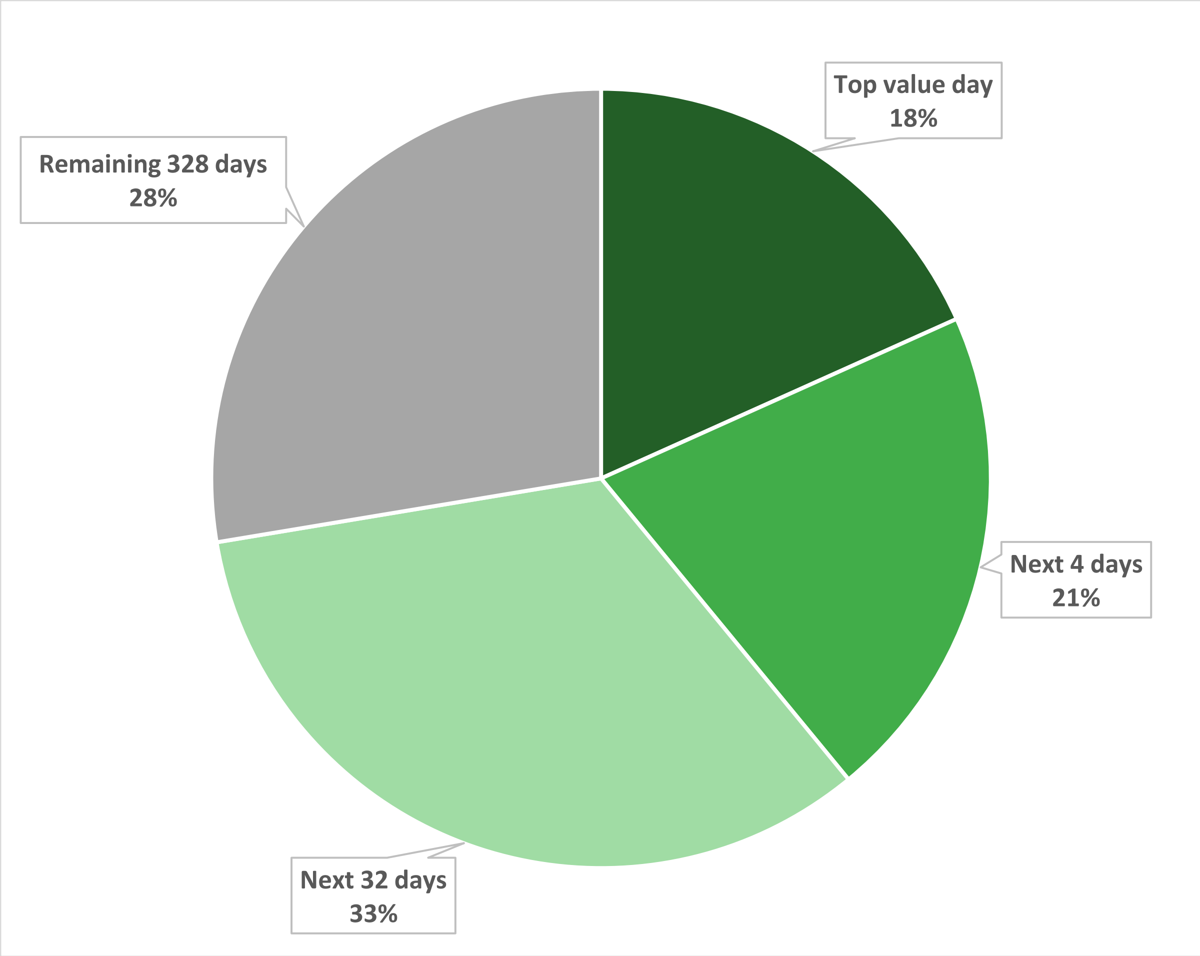


Figure 69: Critical days: impact of highest value days on total in an average year 2009-2020 (QLD)

E.2 Ancillary services

There are many ancillary services required to operate the power grid such as frequency control, voltage control, fault level, and inertia. In Australia only frequency control is actively traded on a market (the "FCAS" market).

In Australia FCAS is traded across eight markets, as described in Table 27. Generally, raise services are higher value than lower services. This reflects that it is easier to reduce a generator's output than increase it. Similarly, shorter time contingency bands are worth more due to the difficulties in responding to events quickly. Energy consumers (and retailers on their behalf) are required to pay for contingency lower services, and generators raise services.

Table 27 Frequency control markets in the NEM

Time domain	Market	Type	Average Price (VIC 06/18 – 06/20)
0-6s	Fast Raise	Contingency	$11.65
	Fast Lower	Contingency	$0.46
6-60s	Slow Raise	Contingency	$8.30
	Slow Lower	Contingency	$0.23
60s-5m	Delayed Raise	Contingency	$7.67
	Delayed Lower	Contingency	$0.36
Regulation	Regulation raise	Regulation	$33.89
	Regulation Lower	Regulation	$15.06

FCAS service prices have increased in variability significantly over recent years, much like energy as is shown in Figure 70.

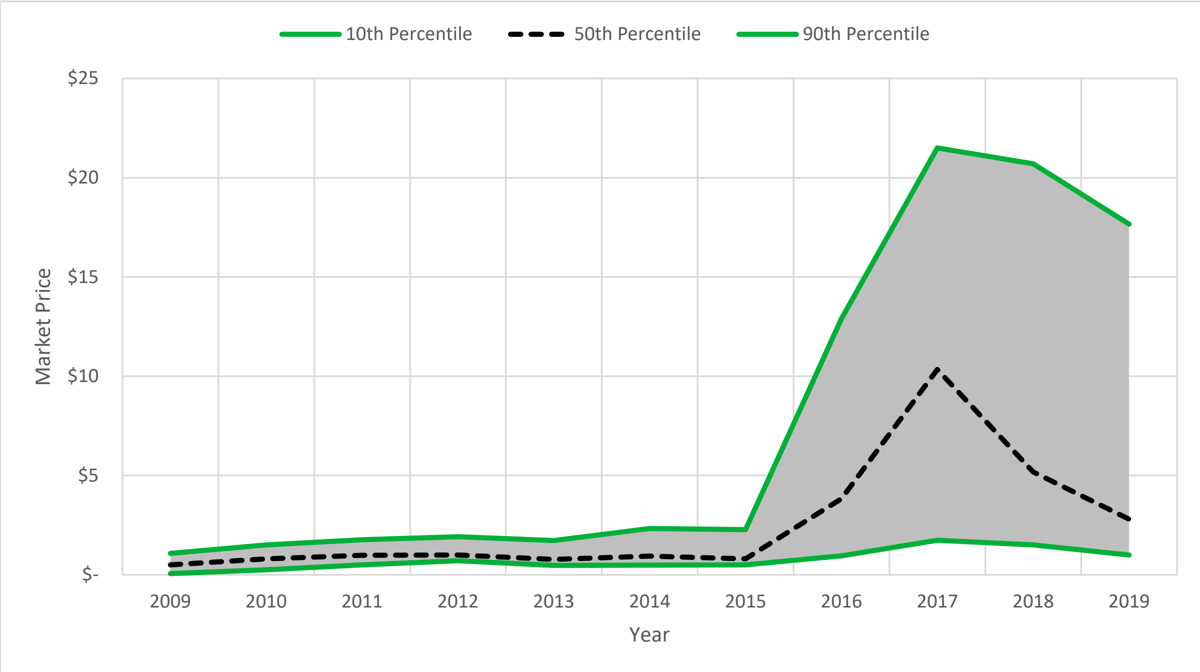


Figure 70 10-90th percentile FCAS R6 price range 2009-2019 (QLD)

Raise FCAS prices tend to follow a similar profile to energy prices while lower prices have a flatter profile. The change in FCAS prices over a day is shown in Figure 71 for raise services and Figure 72.

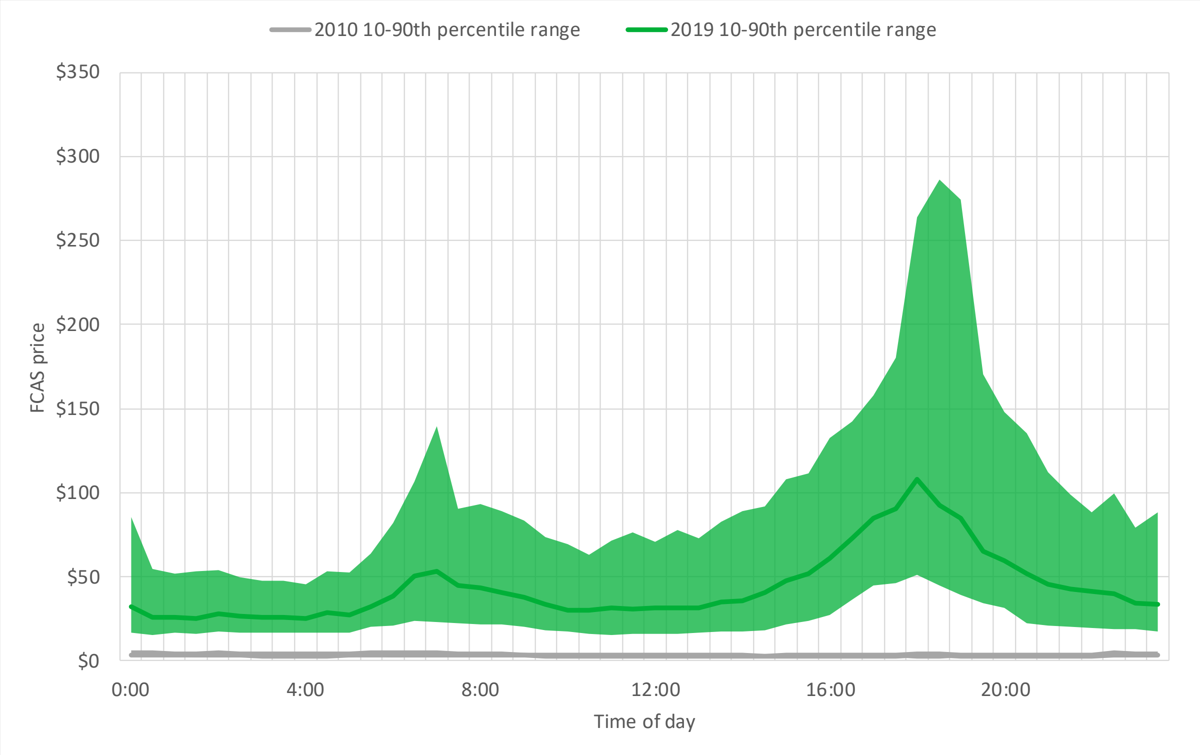


Figure 71 FCAS raise prices over a day - 2010 and 2019 (QLD)

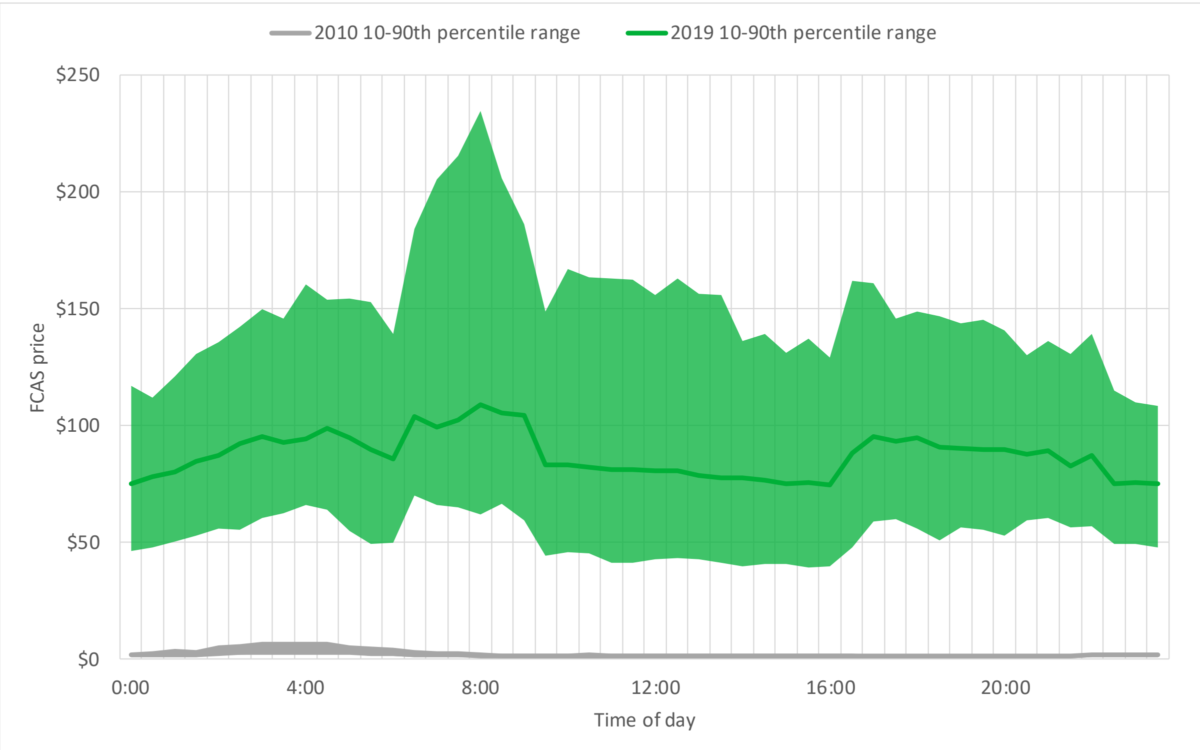


Figure 72 FCAS lower prices over a day - 2010 and 2019 (QLD)

Much like energy, plug in time will impact the amount of value. This is shown in Figure 73.

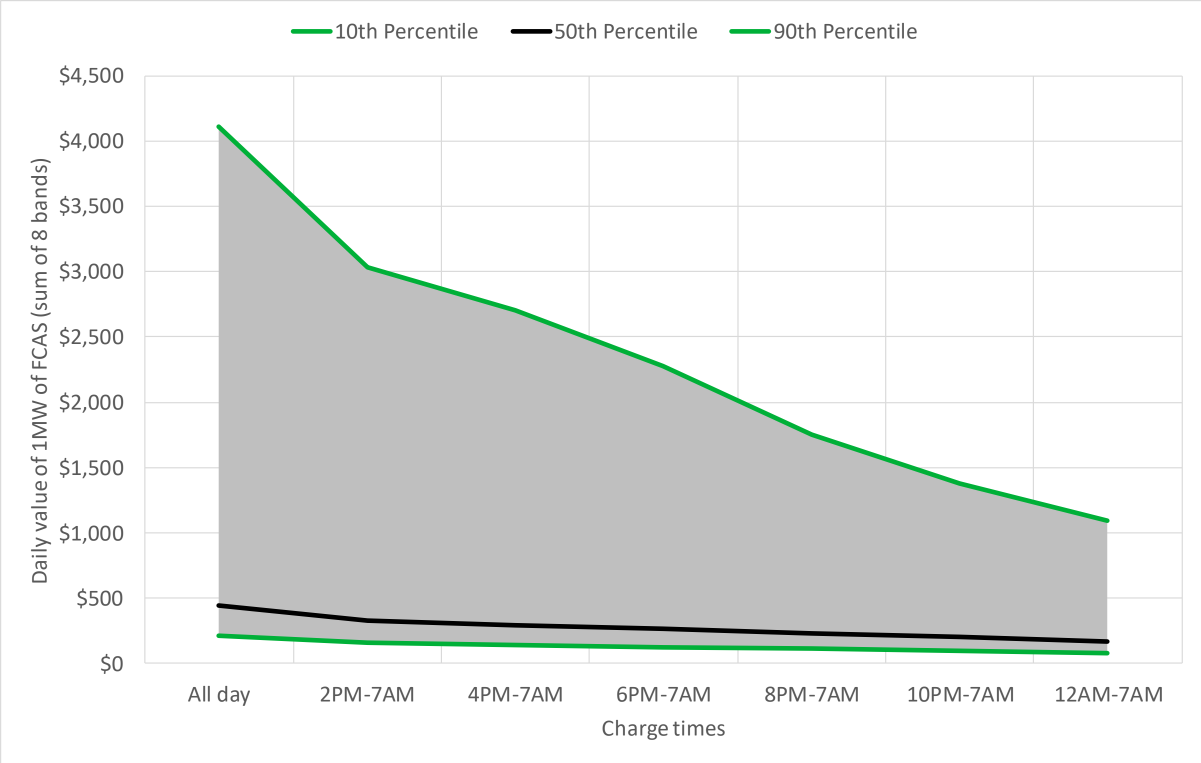


Figure 73 Impact of plug in time on FCAS revenue

In a similar way as for energy high value days strongly impact total value, although somewhat less strongly. This is shown in Figure 74.

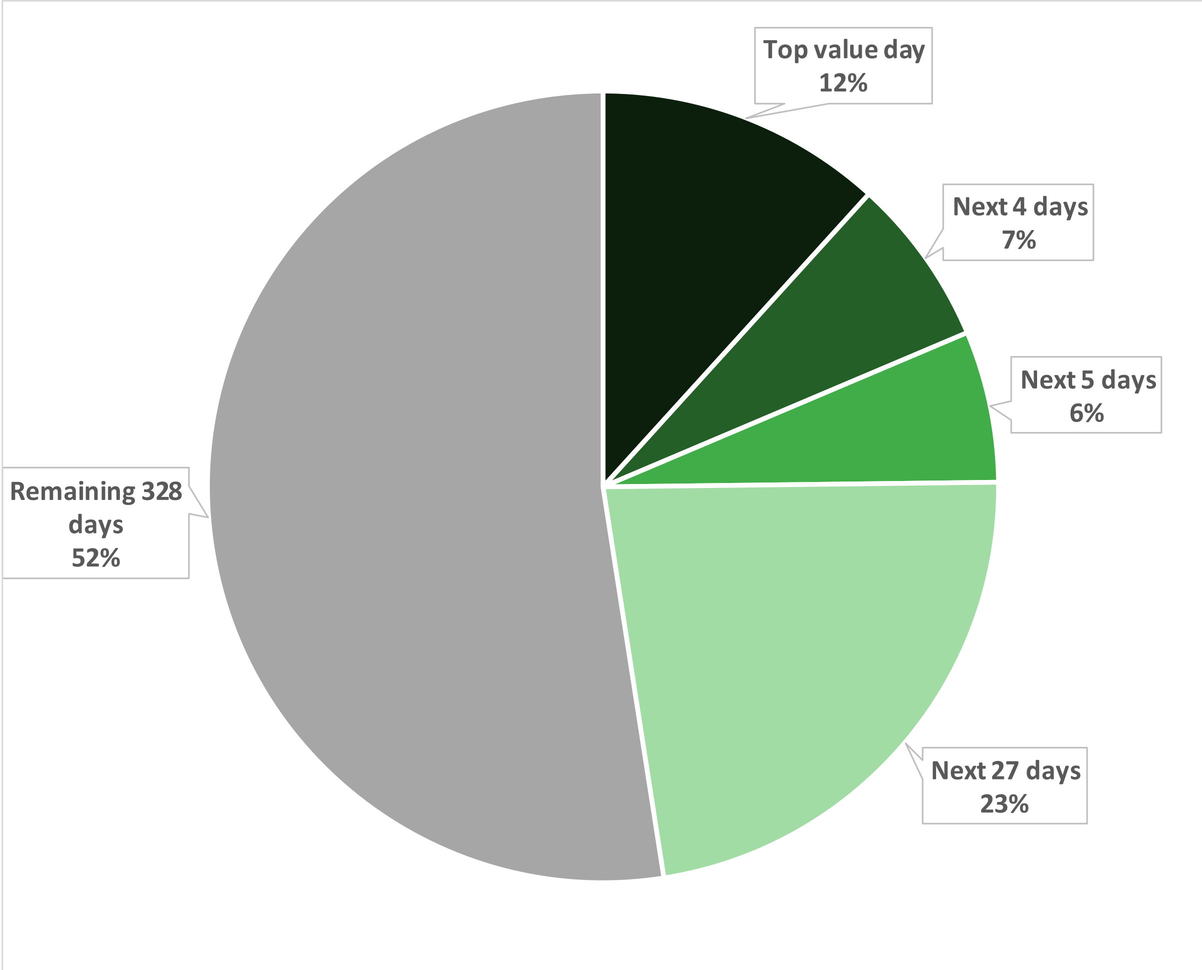


Figure 74 Impact of high value days (FCAS)

E.3 Network congestion management

While the jury is out as to whether EVs will cause a need for significant network investment there will still be times when investment to manage constraints will be required.

Network constraints are not like market prices. They are generally much more constrained geographically, and temporally. This means that utilities will usually make specific requests for demand response services in areas of constraint.

While in some parts of the world these services may be transacted on a marketplace there is no such mechanism in wide use in Australia. Investments that meet costs thresholds (which at time of writing are AUD$6m [316]) must follow the Regulatory Investment Test process. This process requires explicit consultation and testing of the market for demand response solutions [317]. Some networks choose to undergo a similar process for some smaller investments. These provide some modicum of visibility around the value that can be transacted to avoid these investments. A summary of several consultations in Australia are shown in Table 28. Due to the RIT-D requirements these consultations are generally for larger investments which require large amounts of demand response to manage.

Table 28 Summary of recent RIT-D projects

Network (location)	Constraint	Amount and value	Preferred option
Ausgrid (NSW, Australia)	Gillieston Heights [318]	**2019/20:** 190 kVA for ~35 hours/year $51,000 ($268/kVA) **2020/21:** 790-1000 kVA for ~35 hours/year $98,000 ($98-$124/kVA)	Demand response for 2019/20: • air conditioner control • Distributed storage Network reinforcement for 2020/21+ • Interconnection between two feeders • Additional voltage regulation • Capital cost $700k
Ausgrid (NSW, Australia)	Macquarie Park Zone Substation [319]	**2021/22:** 25.6 MW, up to 200 MWh/day $2.05m ($80/kVA)	Network investment comprising a new 132/33kV substation. Capital cost $35.5m
Jemena (VIC, Australia)	Keilor - Tullamarine - Airport West - Pascoe Vale 66 kV sub-transmission loop capacity constraint [320]	**2020/21:** 45.6 MVA $745k ($16/kVA)	Network investment comprising two new 66kV transmission lines. Capital cost $11.2m
Ausnet Services, United Energy (VIC, Australia)	Cranbourne Terminal Station Electricity Supply [321]	**2022/23:** 28.2 MVA precontingent, 133.2 MVA post contingent $1.34m ($475/kVA precontingent, $101/kVA post contingent)	Network investment comprising a fourth 200/66 kV transformer at Cranbourne Terminal Station. Capital cost $26.3m.

The Ausgrid Gillieston Heights project indicates that network-sourced demand response is available for around $268/kVA/year. Other projects have not had successful demand response alternatives proposed or are currently in the consultation phase.

In the UK demand flexibility markets have been adopted more widely by DNSPs. UK Power Networks has awarded 123 MW of flexibility contracts in 2020 for a total value of £14m ($25m AUD, $203/kW) The contract terms are variable between 1 and 7 years [322]. This is a similar order to the value proposed by Ausgrid although it is unclear the mix of contact lengths procured by UKPN. This is for a mix of services as shown in Table 29.

Table 29 Flexibility service types procured by UK power networks

Service	Amount	Types
Secure	49.3 MW	2% DSR, 20% genset, 78% Battery Electric Vehicles
Sustain	1.7 MW	100% Battery Electric Vehicles
Dynamic	72 MW	2% DSR, 42% genset, 56% Battery Electric Vehicles

Western Power Distribution in the UK have standard prices for three different demand response services [323]:

- **Secure:** Manage peak demand on the network
- **Dynamic:** Support the network during planned maintenance
- **Restore:** Support the network after a fault

More dynamic services (Dynamic, Restore) have higher payments due to the shorter notice periods. There are three classes of payment used:

- **Arming:** Paid when a service is expected to be required whether it is used or not
- **Availability:** Payment for readiness to respond
- **Utilisation:** Payment when the service is actually used

Type	Arming	Availability	Utilisation
Secure	£125 ($228 AUD)/MWh	N/A	£175 ($319 AUD)/MWh
Dynamic	N/A	£5 ($9 AUD)/MWh	£300 ($546 AUD)/MWh
Restore	N/A	N/A	£600 ($1092 AUD)/MWh

In 2019 Western Power Distribution procured 543 MWh of flexibility services and spent £547,000 ($995,846 AUD) on these services or an average of £1007 ($1833 AUD)/MWh.

E.4 Expected value from EVs

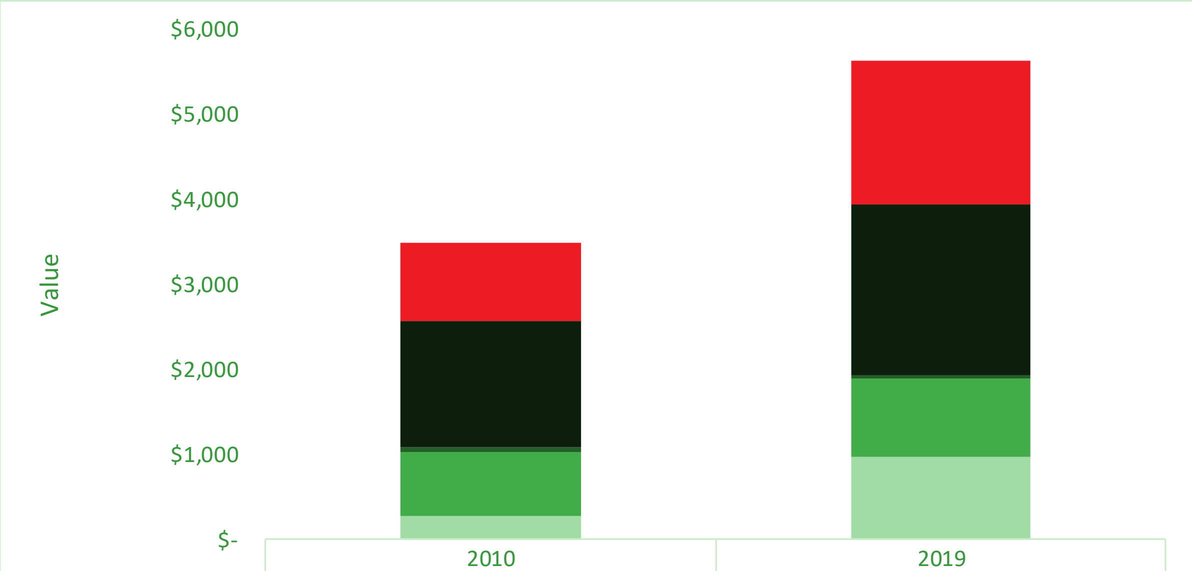
The amount of value that an EV could reasonably attain from the combined market value depends on:

- How often the EV is plugged in
- What it's capacity is when it is plugged in
- What services it is active in
- Constraints on how an EV can be used due to capacity considerations

An indication of potential market benefits for NSW is shown in Figure 75. This chart makes many assumptions that will need to be refined throughout the REVS project. Nevertheless, the indicative numbers can provide guidance in the maximum possible benefit.

- EVs are available outside business hours (9AM-5PM weekdays)
- EVs consume no energy for driving and have a 40kWh battery and 7kW charger
- EVs charge when market price is below average and discharge when it is above average and no capacity is reserved for driving
- All remaining capacity (except for what is used for market price arbitrage) is used for FCAS services
- EVs have no impact on market price and have perfect foresight
- Retail/network charge is ignored

This shows that regulation services are most valuable currently, with contingency raise and energy services of similar order. Between 2010 and 2019 total benefit has increased by 62%, primarily driven by energy arbitrage and regulation services. The total benefits of $5,600pa must be taken in context however, as the frequency control markets are not deep and can easily be swamped by increased capacity, as discussed in the next section.



	2010	2019
Regulation Lower	$922.91	$1,694.02
Regulation raise	$1,479.65	$2,009.99
Contingency Lower	$59.56	$45.13
Contingency raise	$747.46	$915.45
Energy	$279.71	$973.63

Figure 75 Approximate 2019 EV charger market revenue

As discussed in E.3 network congestion management revenue may be around $200/kW/year, or around $1,400/charger/year. This will be highly locational however and bears considerable future value risk if not hedged in a long term contract.

E.5 Future value

While currently there is significant variability in energy price in Australia, an increase in flexible capacity will reduce this [245]. There is significant investment planned in flexible sources of energy and storage such as centralised batteries and pumped Hydro. For example, the Hornsdale Power Reserve in South Australia (SA) reduced FCAS regulation costs by SA generators by 91%, even though it normally only bids 30MW of its 100MW capacity into the market [185]. This change is evident in the number of days with a high FCAS price in SA. Figure 76 shows the FCAS prices in SA with key events annotated. Between the closure of SA's two coal fired power stations (in 2012 and 2016) and the commissioning of Hornsdale Power Reserve in 2018 FCAS prices increased significantly. 2020 has seen an increase in FCAS prices compared to 2019, however. This may be related to high market prices observed in summer 2019/20.

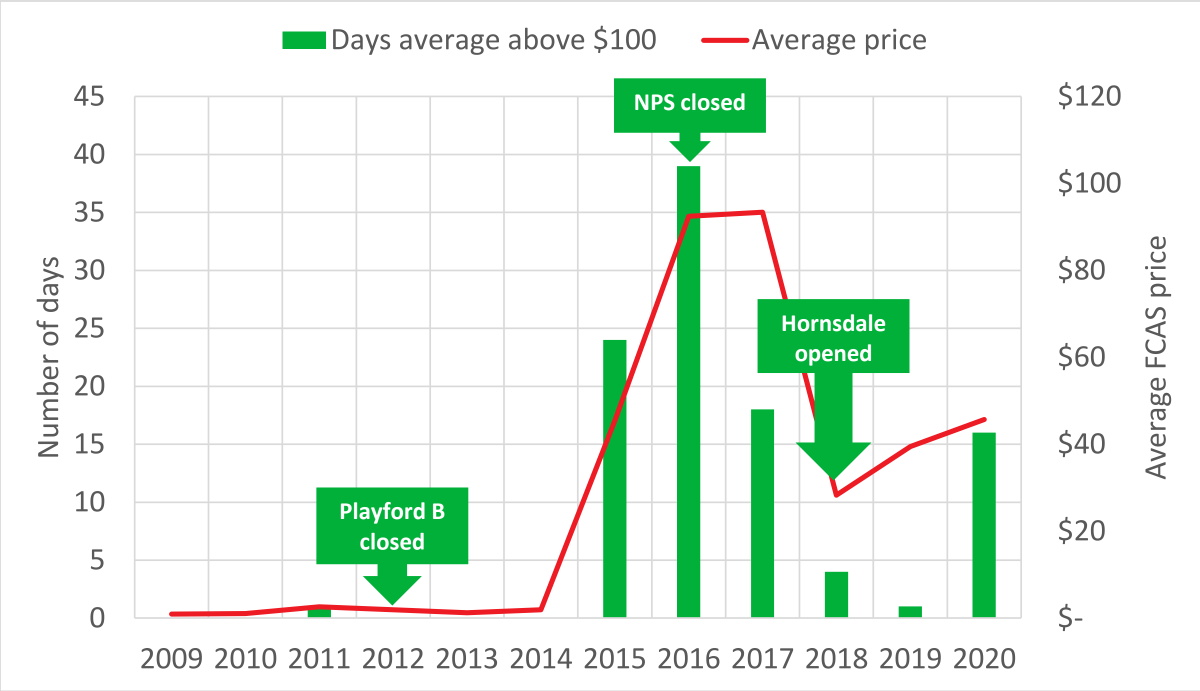


Figure 76: FCAS prices in SA

Appendix F Frameworks of sociotechnical change

To become mainstream, V2G must be understood (in a multitude of ways), be accepted, and be seen to be valuable to a large enough portion of vehicle owners and service providers across the electricity-transport system.

There are several ways of understanding the social and political dynamics of how technologies like EVs and V2G move from 'niche' to mainstream. Three of these are most useful:

1) diffusion of innovation theory,
2) social construction of technology, and
3) the multilevel perspective

These are discussed further below.

Taking these three approaches together helps address their individual gaps. It also allows us to take a holistic view of the wider electrical and transport regimes that V2G and EVs operate within. With this methodology we can retain sufficient granularity to examine the many roles of users in actively adopting, adapting and advocating for the technology in response to the changing socio-technical landscape. This helps us ask questions like:

- 'Why' and 'how' people are making decisions about V2G and EV technology?
- Which incumbents are negatively affected and may oppose the change? and
- How can we ensure fairness, transparency, and trust?

These factors we know are critical to promote social acceptance of new technologies [19].

F.1 Diffusion of innovation

Diffusion of innovation theory describes the social processes of adopting and then communicating about a particular innovation through interpersonal networks and the modelling of its use. Innovations could be a new technology, practice, product or just a new idea. The theory identifies five categories of innovation adopters: innovators, early adopters, early majority, late majority and laggards. These categories are arguably somewhat value-laden, in that they may presuppose pro-innovation values. The theory suggests that people consider a range of personal and institutional factors as part of innovation adoption, including the innovation's relative advantage, compatibility, complexity, trialability, and observability. An adapted model of this decision-making framework is shown in Figure 77.

Diffusion of innovation theory also identifies a number of roles that people may play as they communicate about the innovation:

- **Opinion leaders:** who are influential in their communities,
- **Change agents:** who attempt to influence others, and
- **Re-inventors:** who adapt innovations for their local circumstances [7, 13, 14].

The theory has been criticised, however, for a narrow emphasis on people as buyers, and a static conceptualisation of technology [15].

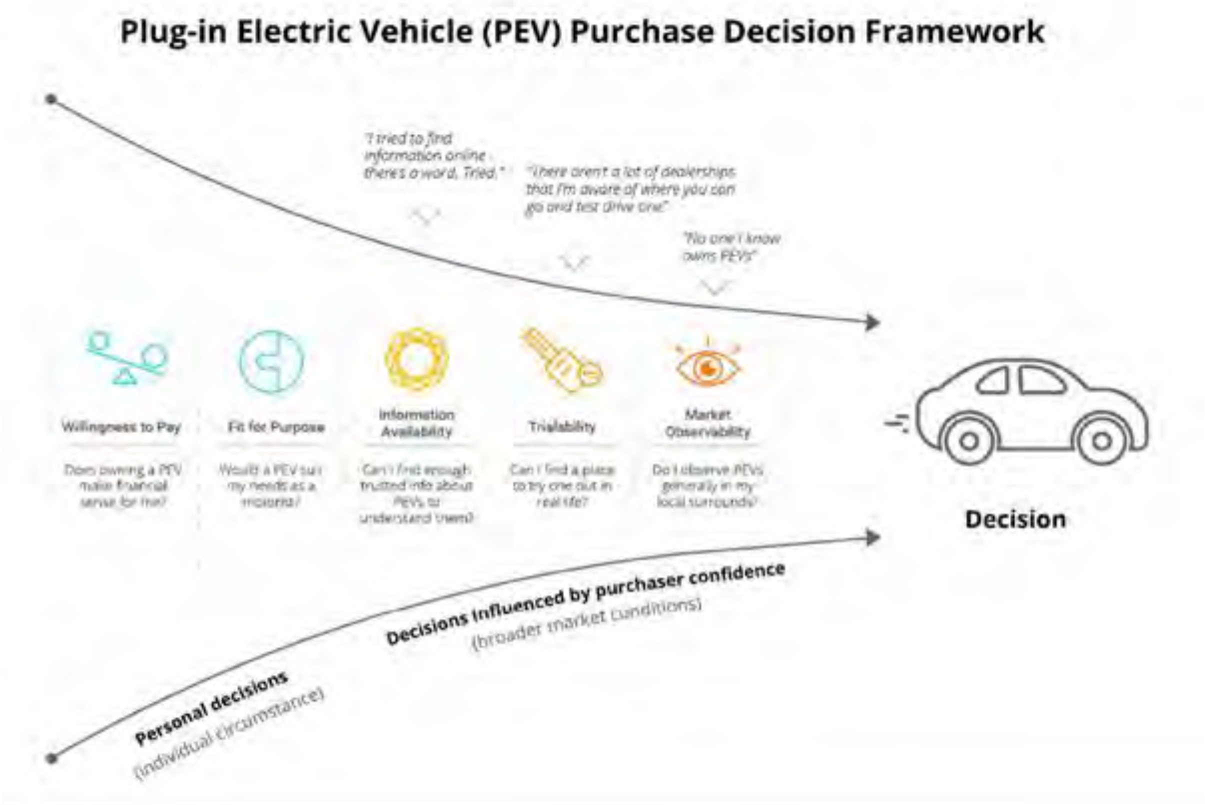


Figure 77 Electric vehicle purchase decision framework, from [13]. Reproduced with permission from the copyright owner.

F.2 Social construction of technology

Social construction of technology theory addresses some of these gaps in diffusion of innovation theory. It argues instead that technologies are fluid, not fixed, and are co-constructed by users. Essentially, this theory argues that social groups embed new technology with meanings through a process called *interpretive flexibility*. In this process social groups embed new technology with meanings, or scripts. These can then shape the technology along with the users themselves and their wider social settings [12]. In section 4.1.1 we have discussed in more detail the kinds of meanings that people may ascribe to EVs and V2G and what effect these may have. There may be considerable scope for this user innovation to creating new scripts and drive uptake of V2G and EV technology.

For example, social construction of technology theory has been used to show how rural Americans adapted the early Model T Ford to provide a source of stationary power and a makeshift tractor on their farms. This sort of adaptation, shown in the illustrated postcard from the time in Figure 78, was initially encouraged by Henry Ford. It opened up a new market for adaptors and conversion kits. These adaptations also smoothed the adoption of the car, which had seen stiff resistance prior to this in rural American communities [16]. The theory has, however, been criticised for overemphasising individual agency at the expense of wider systemic considerations [324], [7], [12].

Figure 78 Illustrated postcard showing the adapted Model T Ford, from [16].

F.3 Multilevel perspective

The need to more fully consider systemic considerations can be addressed in part through the multilevel perspective (MLP). MLP focuses on systemic changes as innovations move from protected *niches*, like pilot projects, to become part of the socio-technical *regime*. The socio-technical regime is a system of knowledge, rules, infrastructures, markets and practices maintained by businesses, engineers, regulators, policymakers, and lobbyists. This regime can limit innovation to incremental, path-dependent change. More radical change can be driven by pressure from the wider socio-technical *landscape,* such as demographic change, shocks, geopolitics. Climate change is a good example of pressure driving more radical change in the case of EVs and V2G [17], [18], [7], [12].

A key strength of the MLP is its recognition that technological change is enacted by multiple groups (e.g. businesses, users, financiers, policymakers, media, academia and activists) engaging in multiple activities (e.g. learning, debate, conflict, negotiation and partnerships). It also identifies a number of user categories, in particular:

- **User-producers and user-legitimators:** who help develop meaning for new technologies through tinkering and reinterpretation,
- **User intermediaries:** who help promote them among others, and
- **User-citizens:** who lobby for changes to the dominant regime [18], [7], [12].

These categories overlap somewhat with those identified by diffusion of innovation theory, as shown in Table 30.

Table 30 Different user roles/processes and their overlap, adapted from [7].

Theory / Role	Diffusion of innovation	Social construction of technology	Multilevel perspective
Promotion	Opinion leader, change agent	Social groups	User-intermediary, user-citizens
Reinvention	Reinventor	Interpretive flexibility	User-producers, user-legitimators

Recent MLP research has focused on regime destabilisation and decline and on ‘phase out’ and just transition policies. This is in recognition that innovation and resulting changes can cause loss of jobs, revenue, and political support. Some researchers have also incorporated discourse theory in recognition that positive and negative narratives can affect acceptance. For example, in the case of carbon capture and storage, windfarms, and smart meters. Discourse theory is also important to understand landscape shocks like the Fukushima Daiichi nuclear power station disaster or the 1970s oil supply crisis.

Appendix G EV charging and energy tariffs

Customers usually pay for energy though a tariff. Energy charges are usually made up of a combination of fixed, energy, and demand components, shown in Table 31. Historically most electricity usage was via flat (any time) energy charges, but this is changing to include more variable energy and demand components [325].

Table 31 Electricity usage pricing components

Component	Metric	Description
Fixed charge	$/day	A fixed daily charge for access to the grid. Customers generally can't reduce this through changing consumption
Energy charge	$/kWh	Charged based on how much energy the customer consumes over a period. May vary with time of day, day of week, or season.
Demand charge	$/kW, $/kVA	Charged based on the customers peak demand[6] within a certain period (commonly monthly). May vary with time of day, day of week, or season.

Time of use electricity tariffs are a common way of reducing EV charging costs [78]. Studies have shown that EV owners will shift home charging to low cost times given a price signal [113]. These products rarely offer active control; instead, customers often implement this control through timers built into most electric vehicle as standard, or through smart chargers they purchase themselves.

Most jurisdictions offer time of use tariffs to customers, although many may not be specifically targeted at electric vehicles. In Australia, time of use rates are available in all states and territories [326]. Some Australian retailers offer electric vehicle specific time of use rates [233, 327, 328] which may offer lower rates than standard time of use products. For example Powershop's "super off peak" electric vehicle rate is 46% cheaper than their standard off-peak rate between 12AM and 4AM every day [329].

In the US over 25 utilities offer special tariffs for electric vehicles, with charging rates up to 95% lower at night [112]. In these products, utilities generally have no active control over charging and rely on the customer electing to charge in low cost periods. Studies have shown a high level of compliance with these price signals, with one study showing these rates 99% effective [113]. Another study showed that 40% of customers on a dual rate tariff used a timer to shift their charging energy to off-peak times [108].

The key driver of the benefit will be the difference between the "off-peak" charging rate and a standard non-time of use energy product. A comparison of selected worldwide rates for a standard residential BEV (3,500 – 4,350kWh/year) [78] is shown in Table 32. It shows that an EV driver may save between $400 and $800/year by choosing an EV-specific or standard time-of-use plan and charging off-peak.

[6] Highest energy consumption within any interval (e.g. 15 or 30 minutes) in a period

Table 32 Impact of EV specific time of use tariffs on total charge cost (all costs in $AUD)

Victoria, Australia (Powershop)	Standard tariff: CitiPower supply area, Victorian default offer [330]	Any time energy: $0.2517/kWh Expected yearly cost (BEV): $881-$1095
	EV specific tariff: CitiPower supply area, Victorian default offer [79]	Super Saver off-peak energy: $0.1177/kWh Expected yearly cost (BEV): $412-$512 ($469-$583 cost reduction)
Tasmania, Australia (Aurora Energy)	Standard tariff: Tariff 31 (Light & Power) [331]	Any time energy: $0.2696/kWh Expected yearly cost (BEV): $944-$1173
	Time Of Use (Non EV specific) tariff: Tariff 93 [331]	Time of use energy: $0.1517/kWh off-peak Expected yearly cost (BEV): $531-$660 ($413-$513 cost reduction)
New York, United States (Con Edison)	Standard Rate [332]	Any time energy: $0.1624/kWh Expected yearly cost (BEV): $568-$707
	EV-specific rate [333]	Time of use energy: $0.0226/kWh off-peak Expected yearly cost (BEV): $79-$98 ($489-$608 cost reduction)
West Midlands, UK (Octopus Energy)	Standard rate [76]	Any time energy: $0.2642/kWh Expected yearly cost (BEV): $925-$1149
	EV-Specific rate [76]	Time of use energy: $0.0905/kWh off-peak Expected yearly cost (BEV): $317-$394 ($608-$755 cost reduction)

Larger customers often have demand charges and these charges are becoming more common for progressively smaller customers. These sorts of prices require a more dynamic approach to charging cost minimisation. If EVs can be charged such that peak demand doesn't increase, fuelling costs can be very low. Some examples using ActewAGL's commercial pricing products are shown in Table 33. The complexity of this will depend on the demand profiles of the customer and the size of the charger. Customers with a flat demand profile such as factories or connections with only chargers attached cannot avoid incurring demand charges for charger load. Customers with a peaky load profile may be able to avoid most demand charges by charging when demand is low.

Table 33 Comparison of business tariff options (4,350kWh/year, 7kW charger) [334]

ActewAGL (ACT) Business (Flat energy)	Energy: $0.3190/kWh (anytime)	Charging in highest cost way: $1388
		Charging in lowest cost way: $1388
ActewAGL (ACT) Business Incentive (Time of use energy)	Energy: $0.3766/kWh (peak) $0.2613/kWh (shoulder) $0.1978/kWh (off - peak)	Charging in highest cost way: $1638
		Charging in lowest cost way: $860
ActewAGL (ACT) Business Demand (Demand + flat energy)	Energy: $0.2173/kWh (anytime) Demand: $0.5034/kW (any time)	Charging in highest cost way: $2231
		Charging in lowest cost way: $945
ActewAGL (ACT) Low Voltage Time of Use Demand (Demand + time of use energy)	Energy: $0.2420/kWh (peak) $0.2075/kWh (shoulder) $0.1760/kWh (off - peak) Demand: $0.5066/kW (any time)	Charging in highest cost way: $2347
		Charging in lowest cost way: $766

A smart charger (V1G/V2G) allows EV drivers to access more dynamic pricing products. This may be through general dynamic pricing tariffs or as part of a bundled service.

In jurisdictions with active energy markets some retailers offer "market price pass through" retail products. For example, Amber Electric in Australia offer a market price pass through energy tariff [75]. Although not focused on EVs, this tariff provides a real time price signal that can significantly reduce charge cost. Amber doesn't currently offer customers a technology solution to assist EV owners manage charging, although some are in development [335].

Alternatively, some retailers may provide customers with a smart charger a favourable fixed rate in exchange for control of EV charging. An example of this is Green Mountain Power. They offered as a trial a plan where customers received a free smart charger and could access unlimited charging for $29.99/month [336]. This was offered as a trial which has now closed. Their current product offers a free charger in exchange for connecting to Green Mountain Power's device management demand response program [337]. This product does not have any ongoing charge pricing offer. Green Mountain Power have several time of use energy rates available with minimum off peak rates of $0.10839 ($0.16 AUD) [338].

In addition to accessing lower-cost charging, V2X-capable charging can take greater advantage of lower tariffs by charging at the cheaper rate and then using the energy stored in the battery to provide on-site power (V2H or V2B). This is generally achieved by shifting peak whole-of-property consumption to off-peak periods using the vehicle's battery or through storing excess solar generation for later usage [101].

Such a system was demonstrated in JUMPSmartMaui (JSM), a smart community project on the island of Maui, Hawaii between 2011 and 2016 [45]. This program included fast EV charging stations and home chargers installed at homes and offices. Charging and discharging of EVs was managed by the utility's integrated distribution management system. Figure 79 shows how V2G shifted consumption to off-peak periods in the JSM project. The red solid line shows charge power before control. The bar graph shows charge power during the project.

This project showed how V2G EV charging shifted demand away from peaks both by scheduling charging and discharging during peaks.

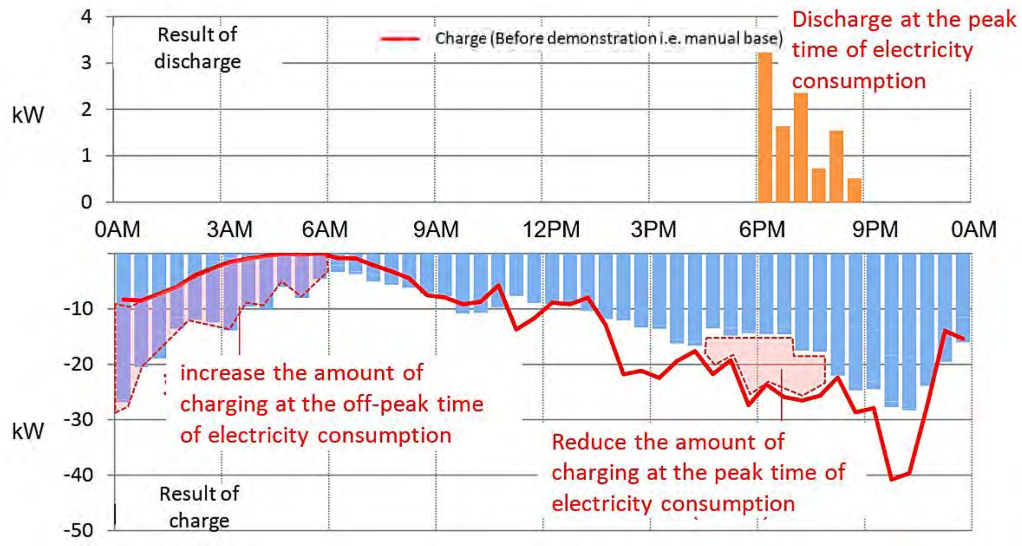


Figure 79: Charging and discharging of EVs in JUMPSmartMaui demonstration [45]. Source: New Energy and Industrial Technology Development Organization (NEDO) "NEDO Smart Community Case Study; JUMPSmartMaui Project.

Appendix H Trials, projects, and intitaives dicussed in this report

This report references several projects and initiatives throughout. This section summarises the projects and the sorts of value that is being investigated or traded within. This is not designed to be an exhaustive list of projects. More complete and up to date lists can be accessed from sites such as https://www.v2g-hub.com/.

Name	Location	Lead organisation	Value traded	Mentioned
Realising Electric Vehicle Services (REVS)	Australia	Evo Energy	Frequency control	Executive Summary, 1
Shift	UK	UK Power Networks	Distribution congestion management	2.2
Project Sicurus	UK	OVO Energy	Energy market price management, Distribution congestion management	2.2, 3.2, 4.1, 5.2, Appendix B
VPP demonstrations	Australia	AEMO	Frequency control	2.2, Appendix C
JuicePlan	Various	Enel-X	Energy market price management	2.2, 3.2, 4.1, 5.2, 5.3, Appendix B
ChargeForward	US (CA)	BMW	Energy market price management	2.2, 3.2, Appendix B
e-flex	UK	Nuvve	Distribution congestion management	2.2
DENSO project	Japan	Denso	Home energy management	3.1
EV V2G school bus project	US	DOE / Blue Bird	Site energy management, emergency power	3.1
SAPN Solar Sponge network tariff	Australia	South Australian Power Networks	Distribution congestion management	3.2
100MW challenge	Australia	Western Power	Distribution congestion management	3.2, 4.2, 5.2, Appendix E
Virtual Cap Contract	Australia	University of Queensland	Energy market price management, Site energy management, Frequency control	3.2, 5.3, Appendix B
Agile Octopus	UK	Octopus Energy	Energy market price management	3.2

Name	Location	Lead organisation	Value traded	Mentioned
PowerShop Super Off Peak EV plan	Australia	PowerShop	Energy market price management,	3.2.1
Parker Project	Denmark	DTU	Frequency Control	3.2, 4.1, 4.2, Appendix A
Los Angeles air force base Vehicle-to-Grid Demonstration	US	Lawrence Berkeley National Laboratory	Frequency Control	3.2, 4.2
Hornsdale Power Reserve	Australia	Neoen	Energy market price management, Frequency Control	3.2.1
My Electric Avenue	UK	EA Technology / Scottish & Southern energy networks	Data, Distribution congestion management	3.2, 4.2
Electric Nation	UK	EA Technology / Western Power Distribution	Data Distribution congestion management	3.2, 3.3, 5.3, Appendix B
EV360	US	Austin Energy	Energy market price management, Transmission pricing reduction	3.2, 3.3, 4.2, 5.2, Appendix B
SHINES	US	Austin Energy	Distribution congestion management, Energy market price management, Transmission pricing reduction	3.2.2
University of California smart charging and V2G demonstration project	US	University of California, Los Angles	Site energy management, Energy market price management, Distribution congestion management	3.2
Ausnet Services Electric Vehicle to Grid trial	Australia	Ausnet Services	Distribution congestion management	3.2
Smartcharge Nashville	US	Tennessee Valley Authority	Data	3.2
Smartcharge QLD	Australia	Energex	Data, Distribution congestion management	3.2, Appendix B

Name	Location	Lead organisation	Value traded	Mentioned
Powerloop	UK	Octopus Energy	Energy market price management, Distribution congestion management	4.1, 5.3, Appendix B
Virtual Peaker	US	Green Mountain Power	Energy market price management	Appendix B
Grid Impact	Australia	Powershop	Energy market price management	Appendix B
Tesla energy plan	Australia	Tesla, Energy locals	Site energy management, Energy market price management, Frequency Control	Appendix B
JumpSmartMaui	US	Mitsubishi Research Institute	Renewable integration	Appendix G