AGL Electric Vehicle Orchestration Trial

Final Lessons Learnt Report

May 2023

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This Project received funding from ARENA as part of ARENA's Advancing Renewables Program.

The views expressed herein are not necessarily the views of the Australian Government, and the Australian Government does not accept responsibility for any information or advice contained herein.

1. Executive Summary

AGL's Electric Vehicle Orchestration Trial has received funding from ARENA as part of ARENA's Advancing Renewables Program. The trial comprised three streams:

- A trial of orchestrated residential electric vehicle (EV) smart charging with 200 participants having their charging controlled via a smart charger installed in their homes.
- A trial of two emerging charging technologies – vehicle Application Programming Interface (API) charging control (100 vehicles) and Vehicle to Grid (V2G).
- A control group of 100 customers on a time-of-use (TOU) tariff to assess the effectiveness of a tariffication incentive against that of firm charging control.

There were no major issues encountered building and operating the smart charger and vehicle API streams of the trial. The test program was implemented successfully and included scheduled and ad-hoc charging control. A comprehensive program of customer research was undertaken during the trial to gauge customer reaction to the charging control and their attitudes towards the technology.

AGL found that the state of readiness of V2G technology during the project timeframe was such that the V2G stream of the trial could not achieve its objectives and could not be executed as proposed. With the agreement of ARENA, this part of the trial was removed from the project through a variation.

The key findings from the project are:

- The overall residential charging load is smaller and more diverse than expected. Only around 16% of home chargers are used every day. The expected early evening peak in charging load is absent from the baseline data.
- Most residential charging occurs overnight, particularly on weekdays.
- EV customers on time-of-use tariffs are already responding strongly to the tariff signals and moving their charging to off-peak periods.
- Charging orchestration is effective in reducing charging demand at peak times, particularly during the evening system peak.
- Customers are receptive to having their charging controlled provided they have the ability to opt out. The opt-outs are rarely used.
- Customer response to the trial was very positive, with 84% indicating they would be likely to sign up to a smart charging service.
- Vehicle API control is a promising technology that provides a high degree of visibility and control of vehicle charging, although some issues remain to be ironed out.
- V2G is at least two to three years away from being a practical reality.

2. Introduction

The AGL Electric Vehicle Orchestration Trial project commenced in November 2020 and received funding from ARENA as part of ARENA's Advancing Renewables Program.

The trial comprised the following streams:

- A trial of orchestrated residential EV smart charging to assess the value of controlled charging as a distributed energy resource – 200 participants who will have their charging controlled via a smart charger installed in their homes.
- A technology trial of vehicle API charging control – 100 participants (expanded from the original 50) with their vehicle charging controlled remotely via an API provided by the vehicle manufacturer.
- A control group of 100 customers on a time-of-use (TOU) tariff whose performance will be compared with the participants on controlled charging to assess the effectiveness of a tariffication incentive against that of firm charging control.

A planned technology trial of vehicle-to-grid charging orchestration was discontinued following significant delays in obtaining regulatory compliance for the charger and technical shortcomings with the proposed solution, meaning the objectives of the trial could not be met. This is covered further in section 5.

There were three phases to the trial:

Phase 1: Recruit and Build – recruitment of all trial participants, installation of charging hardware in homes and development of an aggregation platform to manage and control charging. This phase took place during calendar year 2021 (extended to early 2022 for the second group of vehicle API participants).

Phase 2: Operate – test and trial the various solutions in the field, collate charging data for detailed analysis and carry out customer research. This phase took place during calendar year 2022.

Phase 3: Close-out – transition customers from the trial, analyse the data and publish the final project report. This phase took place in the first half of 2023.

The trial delivered a number of interesting, and in some cases unexpected, outcomes, which are covered in detail in the following sections. In examining these outcomes, however, some aspects of the trial sample population that may have influenced trial results should be borne in mind:

1) The vast majority of the trial participants fell into the "innovator" or "early adopter" categories[1]. This is an unavoidable result of the type of drivers owning EVs in Australia in 2021, at the time recruitment for the trial was being undertaken. To what extent the behaviour and attitudes of this sample reflects the behaviour and attitudes of the broader population is difficult to judge,

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[1] https://www.business.qld.gov.au/running-business/growing-business/becoming-innovative/innovation/categories-customers

however the trial participants were certainly highly engaged in relation to vehicle charging and energy supply generally.

2) Participants in the smart charger stream of the trial received a free charger[2]. Although all trial participants owned an EV, very few had invested in a home charger before the trial. Although this is not likely to be a big influence on behaviour across the full trial population, it is possible that the charging behaviour of some trial participants may not be reflective of the behaviour of customers who bought a charger themselves.

3) Tesla vehicles and drivers were over-represented in the population sample – 62% of smart charger stream participants and 100% of the vehicle API stream. This reflects the very high penetration of Tesla vehicles in the Australian market and the fact that Tesla was the sole EV manufacturer offering API charging control in Australia at the time of the trial. However, due to their high-technology nature, Tesla vehicles tend to appeal to more technically savvy drivers whose behaviour may not reflect that of the broader population.

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[2] A small number of participants with complex installations contributed to the cost, but the charger and installation was heavily subsidised in all cases.

3. Trial Results – Smart Chargers

3.1. Trial operation

The installation and operation phases of the smart charger trial were completed successfully and with very few technical issues. Scheduled and ad-hoc control of the smart chargers in the field worked well.

AGL executed three experimental fixed-time charge schedules over 12 months that the trial ran. The charge schedules were selected taking into account the following factors:

1) An analysis of National Electricity Market (NEM) wholesale prices over time, with a view to supressing charging during periods that prices were likely to be high, particularly during summer.

2) Broad alignment with the evening peak period that Distribution Network Service Providers (DNSPs) have advised can be problematic for the distribution network on hot days.

3) Keeping the scheduled charging times clear of Time of Use (TOU) tariff rate changes that typically occur around 11:00pm (or later). While in the longer term, post-trial, it may make sense to align charger control with TOU rate changes, for the trial it was important to be able to identify load changes due to controlled charging within the trial separate to other actions that customers may have undertaken to move their charging to off-peak times, such as implementing charging controls in the vehicle.

The first charging schedule operated from mid-January to mid-June 2022. It comprised a single charging suppression event of four hours duration in the evening on weekdays:

State	Time reference	Morning		Evening	
		Off	**On**	**Off**	**On**
Qld	Summer	-	-	16:30	20:30
	NEM	-	-	16:30	20:30
NSW	Summer	-	-	17:30	21:30
	NEM	-	-	16:30	20:30
Vic	Summer	-	-	17:30	21:30
	NEM	-	-	16:30	20:30
SA	Summer	-	-	17:30	21:30
	NEM	-	-	17:00	21:00

Charge Schedule 1

When daylight savings time changed to winter time in New South Wales, Victoria and South Australia at the end of March, the charger control times seen by the customers remained the same; that is to say the charging suppression moved an hour later in NEM time for those states. This was done so that the customers didn't need to adapt to a new time regime so early in the trial. The daylight savings time transition was managed by the Chargefox platform without any manual intervention required. This time change does mean, however, that some interpretation is necessary when analysing the data from this schedule after March due to the smearing of on/off times across the states.

The second charging schedule was implemented in mid-June and ran until mid-October:

State	Time reference	Morning		Evening	
		Off	On	Off	On
Qld	Winter	5:30	9:30	16:30	20:30
	NEM	5:30	9:30	16:30	20:30
NSW	Winter	5:30	9:30	16:30	20:30
	NEM	5:30	9:30	16:30	20:30
Vic	Winter	5:30	9:30	16:30	20:30
	NEM	5:30	9:30	16:30	20:30
SA	Winter	5:30	9:30	16:30	20:30
	NEM	6:00	10:00	17:00	21:00

Charge Schedule 2

This schedule re-aligned the evening charge control times in the eastern states (30 minutes later in SA), and added a second four hour period of charging suppression in the morning, making a total of eight hours of charging suppression each weekday.

The intention of this schedule was to begin to steer more charging into the middle of the day when solar generation is greatest, and to prevent charging during the second peak in wholesale pricing that often occurs in the morning.

A third charging schedule ran from mid-October until the completion of the controlled charging trials at the end of December 2022:

State	Time reference	Morning		Evening	
		Off	On	Off	On
Qld	Summer	5:30	9:30	15:30	20:30
	NEM	5:30	9:30	15:30	20:30
NSW	Summer	6:30	10:30	16:30	21:30
	NEM	5:30	9:30	15:30	20:30
Vic	Summer	6:30	10:30	16:30	21:30
	NEM	5:30	9:30	15:30	20:30
SA	Summer	6:00	10:00	16:00	21:00
	NEM	5:30	9:30	15:30	20:30

Charge Schedule 3

This schedule further extended the total time charging was supressed across the day to nine hours, four hours in the morning and five hours in the evening. It reduced the daytime (solar) charge period from seven hours to six hours, better matching the typical peak solar generation curves that occur year-round across the NEM states. Whilst this did not necessarily match actual solar generation times in, for example, Queensland during summer (as pointed out by a couple of trial participants), the intention was to test how far the charging suppression could be pushed without having a negative effect on vehicle amenity, rather than matching actual solar generation during the trial.

This schedule also aligned the charging times in NEM time across all the states. Again, while this alignment might not be optimal in a real implementation, it does improve the intelligibility of the data in the trial situation as the whole population of trial chargers were now doing the same thing at the same time.

For the first time during the trial, the third charging schedule also extended charging control to seven days a week. The previous schedules had been weekdays only.

3.2. Key statistics

Trial population:

200 customers at the start of the trial[3]

[3] There was a 10% reduction in trial participants during the trial across both the smart charger and vehicle API streams, mostly due to retail churn.

34% had a TOU tariff

77% had rooftop solar

During the 12 months of the controlled charging trial (the 2022 calendar year), the smart charging platform recorded:

329MWh of energy delivered

153,272 hours of charging

26,354 plug-in/plug-out charging sessions

87,222 hours of parked time

3.3. Trial Outcomes – Smart Charger Stream

3.3.1. Key findings

- The overall charging load is much smaller and more diverse than expected. Very few customers charge at home every day.
- The average maximum demand per charger in the trial was 450W (during the baseline period when charging was not controlled), which occurred at the onset of the off-peak period in the late evening driven by charger switching by TOU customers.
- Uncontrolled charging load is substantially flat from late morning through to late evening on weekdays. The expected early evening charging peak is completely absent from the data.
- Most residential charging occurs overnight, particularly on weekdays. Whilst customers with rooftop solar charge more during the day than other customers, the majority of their charging still occurs outside solar hours.
- Customers on time-of-use tariffs are already responding strongly to the tariff signals and moving their charging to off-peak periods.
- Charging orchestration is effective in reducing charging demand to nearly zero when it is called upon, and can have a significant impact during the evening system peak.
- Customers are receptive to having their charging controlled provided they have the ability to opt out of the control and turn their charging back on at any time. In practice, the level of opt-outs is very low.

3.3.2. Baseline charging behaviour

Following the completion of the smart charger aggregation platform in August 2022, and prior to charging control being turned on in January 2022, AGL collected baseline data during October, November and December 2021. During this period, the chargers were under the sole control of their owners.

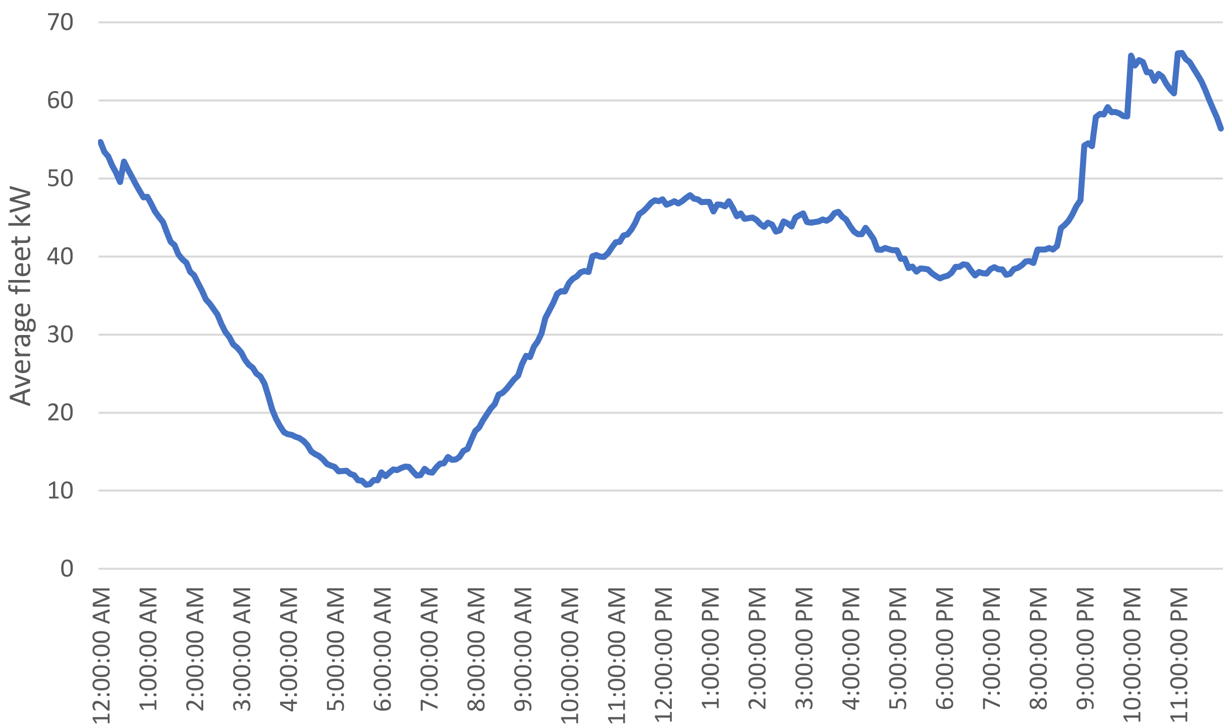
Unfortunately, this baseline data had several issues:

1) Chargers were still being installed at this time, so the sample population was changing across the period.

2) Some chargers exhibited early communication problems and some customers encountered issues initially logging into the app and being recognised by the aggregation system. These problems were still being understood and rectified during this period, delaying the enrolment of these chargers into the aggregation platform and the collection of data from them.

3) The period was heavily covid-affected, with some states still in lockdown at the beginning of October and work-from-home recommendations applying throughout the period.

Consequently, AGL decided to collect further baseline data during January, February and March 2023, immediately following the main trial test program. Although it's possible that some customers may have had their charging behaviour influenced by participating in the trial during 2022, the 2023 baseline data is believed to be more reliable than that from 2021 and is used in the rest of the analysis[4]. This baseline, taken well after lockdowns and government work-from-home mandates finished, should be free of major covid influence and, at the very least, would represent "the new normal" for commuter traffic and work-from-home activities.



Overall baseline charger load shape, all days, January to March 2023.

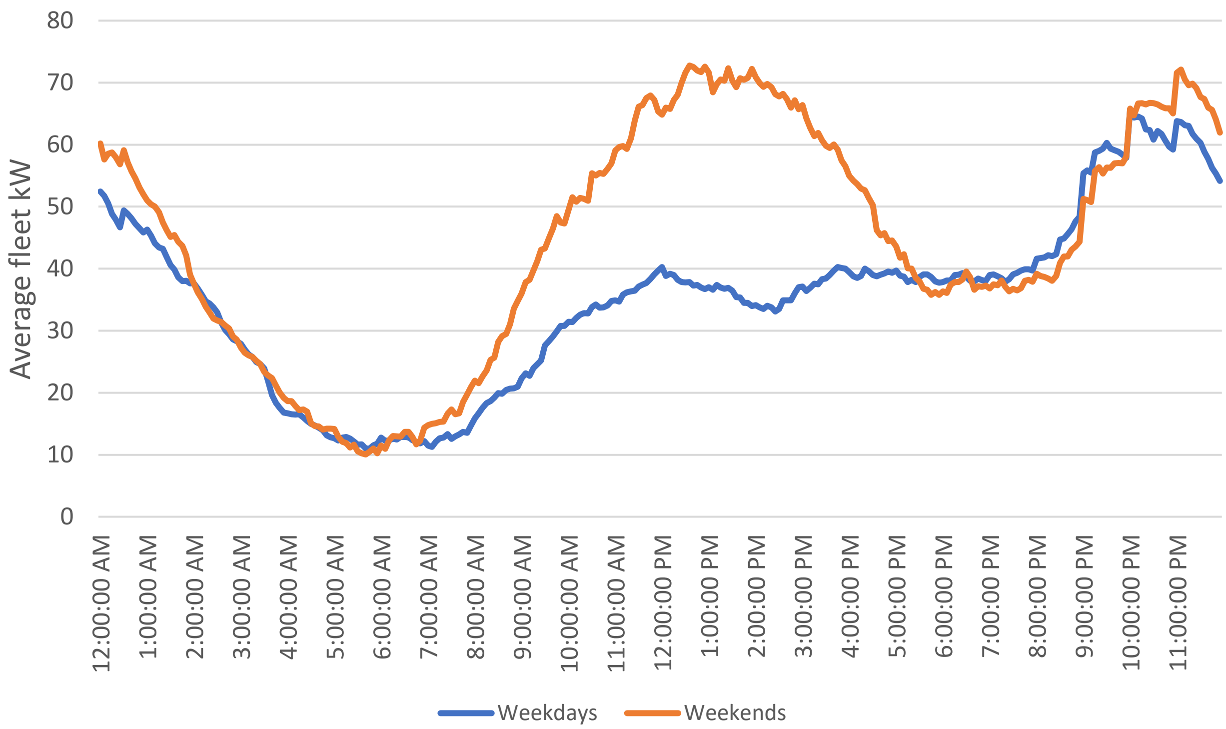
[4] In fact there is very little difference between the two sets of data and the same patterns are apparent in both.

There are several notable things about the overall baseline of charger load:

- The expected evening charging peak around 6:00pm is completely absent.
- There is a marked increase in charging load between 9:00pm and 11:00pm NEM time. In local time this is an hour later for most of these customers (ie 10:00pm to midnight), and half-an-hour later or the same time for the smaller number of customers in SA and Qld. The increase in charging after 9:00pm suggests that a proportion of customers are self-managing the charging hours of their car and deferring their charging to either an actual or nominal[5] off-peak period. This is most likely being achieved with the charging management system in the vehicle. Customer response to TOU tariffs is covered further in section 3.3.3.
- As expected, there is a steady decline in charging load throughout the night as vehicle batteries become fully charged.
- Charging demand is very low in the early morning between 5:00am and 8:00am. By this time, almost all batteries are full and any new charging for the day has not commenced. This suggests that our trial of early morning charging suppression, designed to avoid charging during the morning household peak, was largely unnecessary as there is very little charging happening during this period anyway.
- The average charging load is relatively flat between 10:00am and 9:00pm, within +/- 10%.

There is, however, a significant difference in the baseline charging load between weekdays and weekends.

[5] During customer research, a small number of customers reported that they moved their charging to the off-peak period even though they were not on a time-of-use tariff.



Baseline charger load shape separated into weekdays and weekends, January to March 2023.

- Weekday charging load is relatively flat from late morning to late evening.
- On weekends there is more charging generally, with highest average charging load (72kW for the trial fleet) occurring on weekends.
- The weekend charger load shows a broad peak during the day from 10:00am to 5:00pm NEM time, with a maximum load roughly equal to the narrower peak at 11:00pm.
- Not only is there no early evening charging peak on weekends, there's actually a trough.

3.3.3. Effect of TOU tariffs

TOU tariffs can be a powerful means to encourage customers to move energy use from periods of high cost to periods of low cost, however their history of success in the residential setting is mixed. This is because most household appliances need to be operated at the specific time the customer needs the service; for example if a customer wants to cook dinner, it's necessary to turn the stove on at dinner time. The exception to this are loads with an inherent storage nature to them, such as storage water heaters, where the use of the output of the device (hot water) can be disconnected in time from the consumption of the energy needed to create that output.

The storage nature of electric vehicles, via the energy stored in their battery, presents another opportunity for the application of TOU tariffs in the residential setting. This is because the use of the vehicle (driving around during the day) is disconnected in time from its consumption of energy (charging overnight or at some other time that the vehicle is not being used). Provided there is a mechanism available to easily control the time that charging occurs, customers can take advantage of a

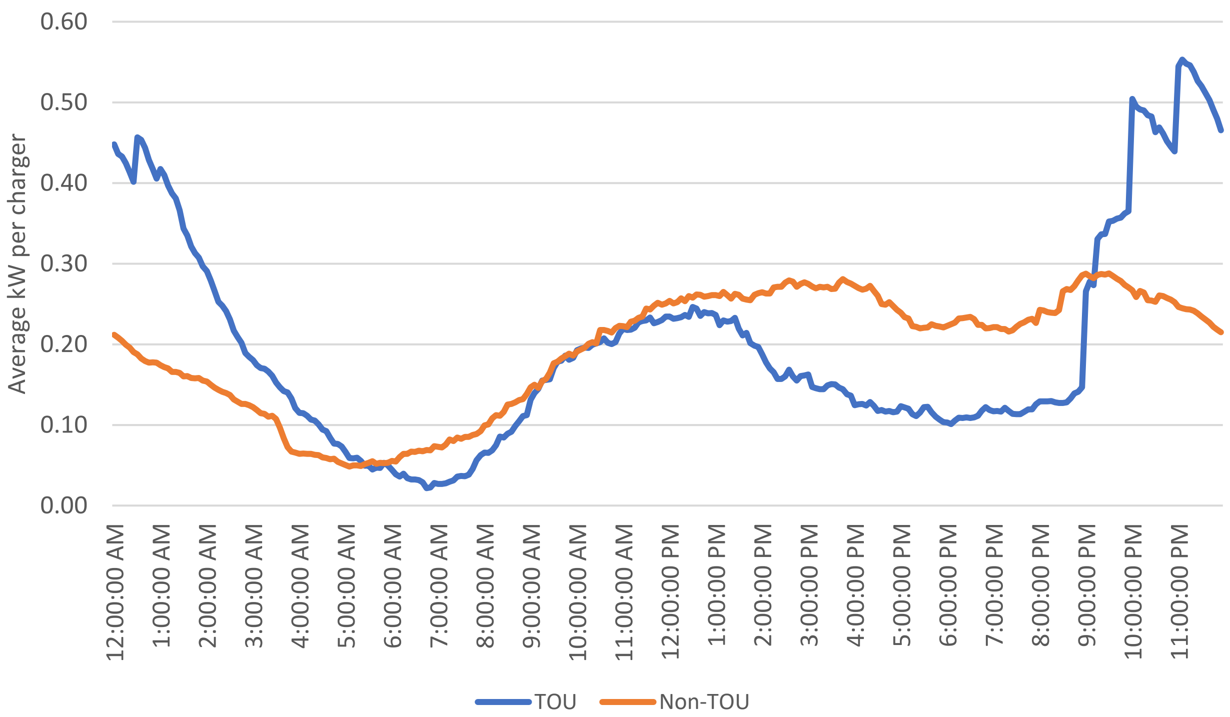
TOU tariff to charge a vehicle at a lower cost without having any negative effect on the utility of the vehicle.

Fortunately, most EV manufacturers have built a mechanism to control charging times into the vehicle itself, usually set via the screen on the dashboard or via the manufacturer's phone app.

In the trial, 34% of customers had a TOU tariff, the remainder were on a flat-rate tariff.

AGL has used the baseline data from the installed base of 200 smart chargers in the period January – March 2023, when there was no control of charging taking place, to examine the underlying response of customers to TOU tariff signals.

The original intention for our TOU study had been to use a separate control group for this purpose, however the control group data has been found to be less than ideal for assessing charging behaviour because it was obtained from the smart meter at the connection point and therefore has other household loads and, in most cases, solar generation mixed in. It's therefore quite difficult to determine the charging load with any accuracy. The data from the smart charger group was measured directly at the charger, however, and provides a much more accurate picture of charging behaviour.

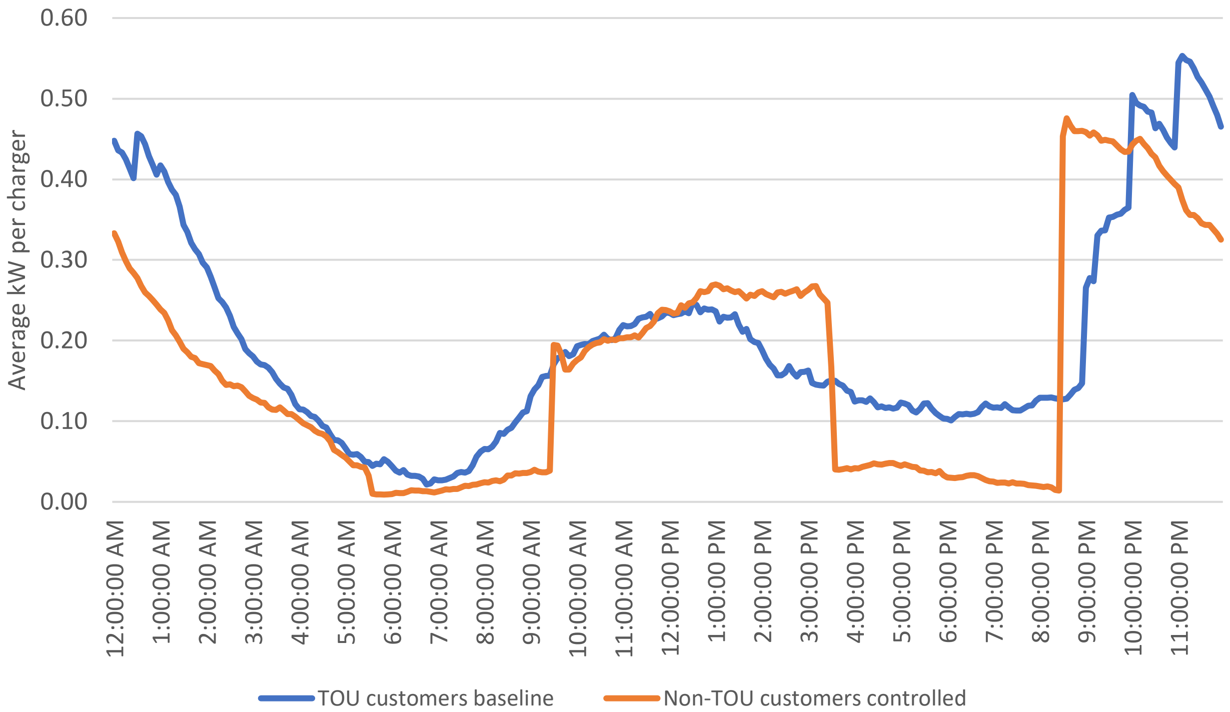


Baseline average per-charger load shape for TOU and non-TOU customers, January to March 2023.

Separated between TOU and non-TOU customers, the baseline data shows clear management of charging by TOU customers in the late evening, with a strong peak commencing at 9:00pm and further peaks after that as customers in the various network areas commenced charging[6]. TOU customers had an average charging load half that of non-TOU customers during the evening system peak.

In most cases, charging was time-shifted using the charging control functionality built into the vehicle. A small number of customers reported that they physically plugged the vehicle in at start of the off-peak period.

Comparing the charging load for TOU customers to those on the controlled charging schedule (schedule 3), there is a close resemblance in the curves, although the controlled charging was slightly more successful in moving the load away from peak periods generally, and the early evening peak particularly.



TOU customer baseline behaviour vs non-TOU customers with charging controlled (schedule 3).

Note that for schedule 3, the evening resumption of charging was set for 8:30pm NEM time, not because this was necessarily the best time to resume charging, but because it aided visibility of the load changes occurring directly because of the control. There is no doubt that this evening resumption of charging could be set to 10:00pm, 11:00pm or even later with no adverse effect on vehicle amenity or

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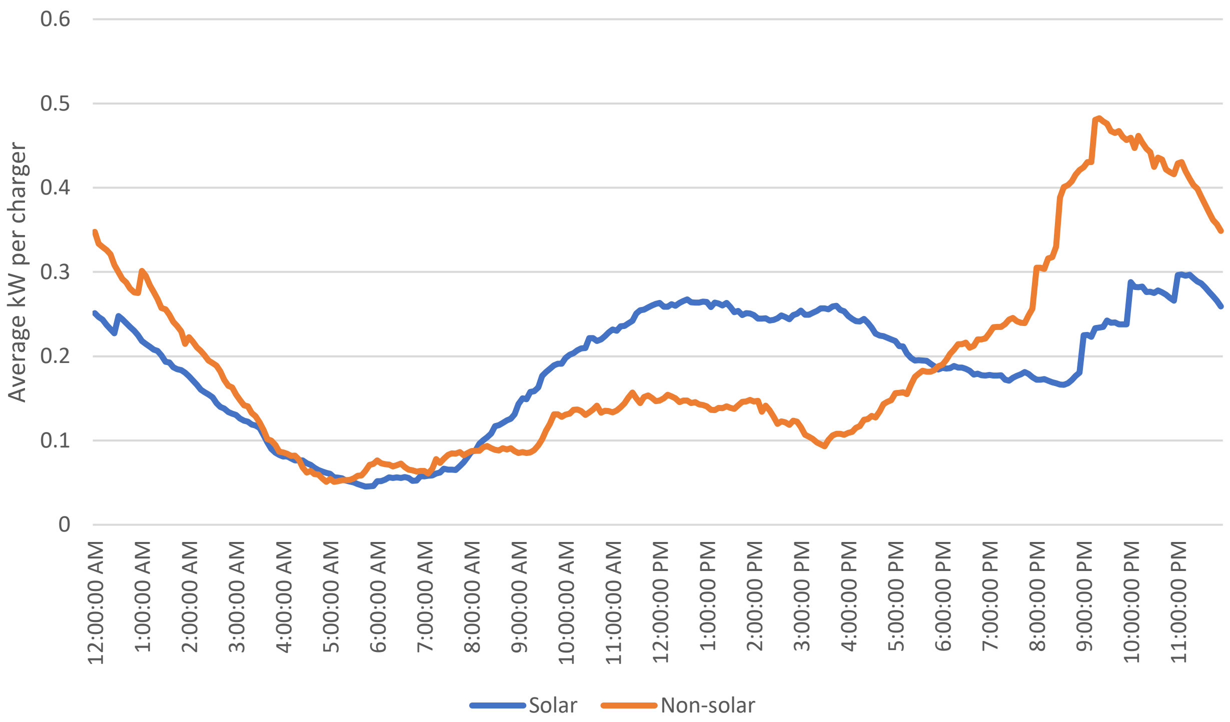
[6] When referenced to NEM time, off peak periods vary between network areas and, in some cases, between weekdays and weekends. The earliest off-peak start time was 9:00pm and the latest 1:30am during the period shown.

impact on customers. If that were done, the overnight load shape would closely match the overnight load shape of the TOU customers.

3.3.4. Rooftop solar customers and EV charging

77% of customers in the smart charging stream of the trial had rooftop solar. From the baseline data, it's clear that many of these customers are charging as much as possible when the solar panels are generating, with the average charging load of solar customers being 80% higher at midday than non-solar customers.



Baseline average per-charger load shape for solar and non-solar customers, January to March 2023.

However, even though solar customers charge more during the day, the maximum charging demand for solar customers still occurs late in the evening when the off-peak rate for TOU tariffs commences, and there remains a significant amount of charging occurring overnight. Solar customers only consumed 31% of their total charging energy during the peak solar hours of 9:00am to 3:00pm NEM time; 69% of charging energy was consumed outside these times, when solar generation would have been negligible. This energy would have come from the grid or, for the small number of customers that had them, possibly from a home battery[7].

[7] Twelve customers in the trial had a home battery.

The reason for the low percentage of charging energy coming from solar is probably two-fold. Firstly, there may not be enough solar generation available from the rooftop panels to meet the overall energy requirements of driving (net of other daytime household loads). Secondly, having the vehicle at home and plugged in during solar hours may, in many cases, be incompatible with its use for transport.

It should be noted that this baseline data was collected during the January – March quarter, the time of year when solar generation is usually at its strongest. It's likely that the utilisation of solar generation for EV charging would be even lower than this in the April – June and July – September quarters, particularly in the southern states.

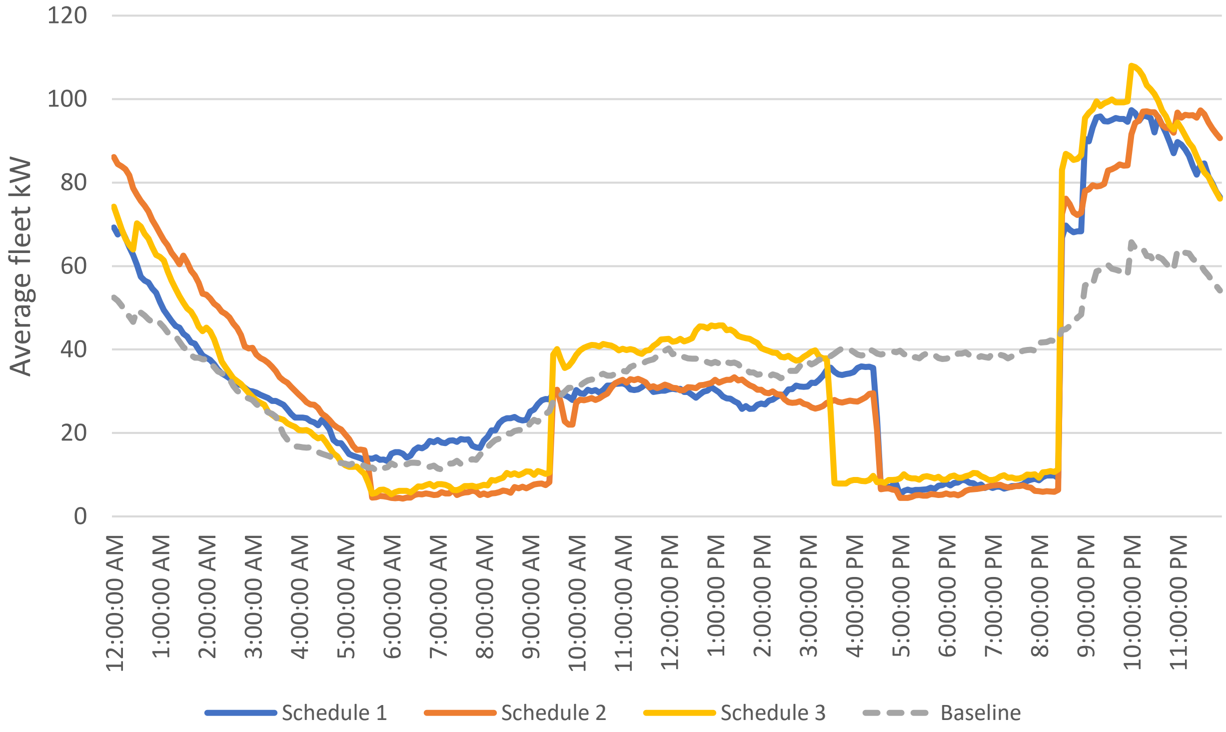
None of the chargers installed for the trial had built-in solar coordination capability, as this functionality was not available in production smart chargers at the time the trial commenced. At the time of writing this report, solar coordination is just starting to become available in a small number of chargers on the market[8]. It's unclear to what extent this functionality would improve the utilisation of solar energy for vehicle charging, as the key issues of solar generation capacity and vehicle driving patterns would remain.

3.3.5. Charging control works to reduce demand at peak times

The trial has clearly demonstrated that controlling home chargers remotely using the OCPP protocol is effective in reducing demand at peak times.

The following graph shows the average weekday results from the three controlled charging schedules tested during the trial, plotted together with the weekday baseline:

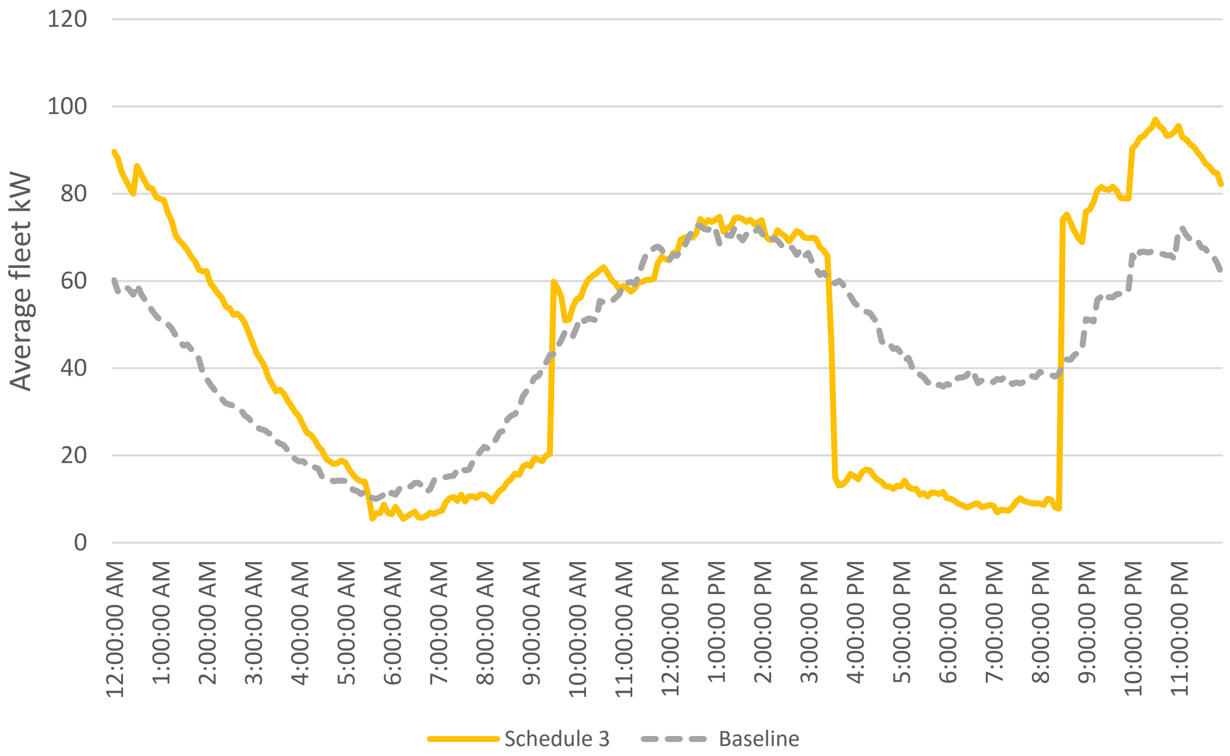
[8] Solar coordination also requires current transformers to be installed at the main switchboard.



Weekday average kW demand for the three controlled charging schedules vs baseline.

- All three schedules were effective in reducing the charging load significantly during the evening peak period, from 40kW to around 5 – 9kW, in the order of 80% or more load reduction. The result from schedule three was marginally worse than the others due to the slightly higher opt-out rate discussed in section 3.3.7, but still resulted in a 78% load reduction.
- All three schedules resulted in a significantly higher post-event demand when the chargers came back on, with the load around 60% above baseline. This occurs at the time the overall system load reduces following the evening peak. This post-event demand peak was highest with schedule three, which suppressed charging the longest. If the peak itself became a problem at a network or system level, it could easily be reduced by randomising the on-time over an hour or two. The fact that nearly all chargers have stopped charging by 5:00am suggests that this would be possible without affecting vehicle amenity.
- All three schedules increased the amount of charging occurring through the early morning hours.
- Schedule two and three reduced demand during the morning peak, but the effect was not significant as there was only minimal charging taking place at that time anyway. (Schedule one did not include morning charging suppression.)
- With slightly longer evening charging suppression, schedule three was slightly more effective in pushing charging into the solar soak period in the middle of the day. However, the impact was minimal, with customers still doing the vast majority of their charging overnight. At least on weekdays, the vision of EV drivers all charging their cars from solar energy appears some distance from reality.

Schedule three also supressed charging on weekends:



Weekend average kW demand for Schedule 3 vs baseline.

- In the evenings, charging control was as effective as it was on weekdays, again pushing most charging out until after 8:30pm NEM time. The effect of the increased opt-outs on weekends under this control schedule can be seen, however, as the lowest level of charging achieved is slightly higher than with the other schedules, particularly in the 3:30pm – 6:00pm timeframe.
- Charging suppression in the morning didn't significantly move the curve from baseline, except to slightly delay the natural increase in charging as the morning progressed.

3.3.6. Ad-hoc charging control

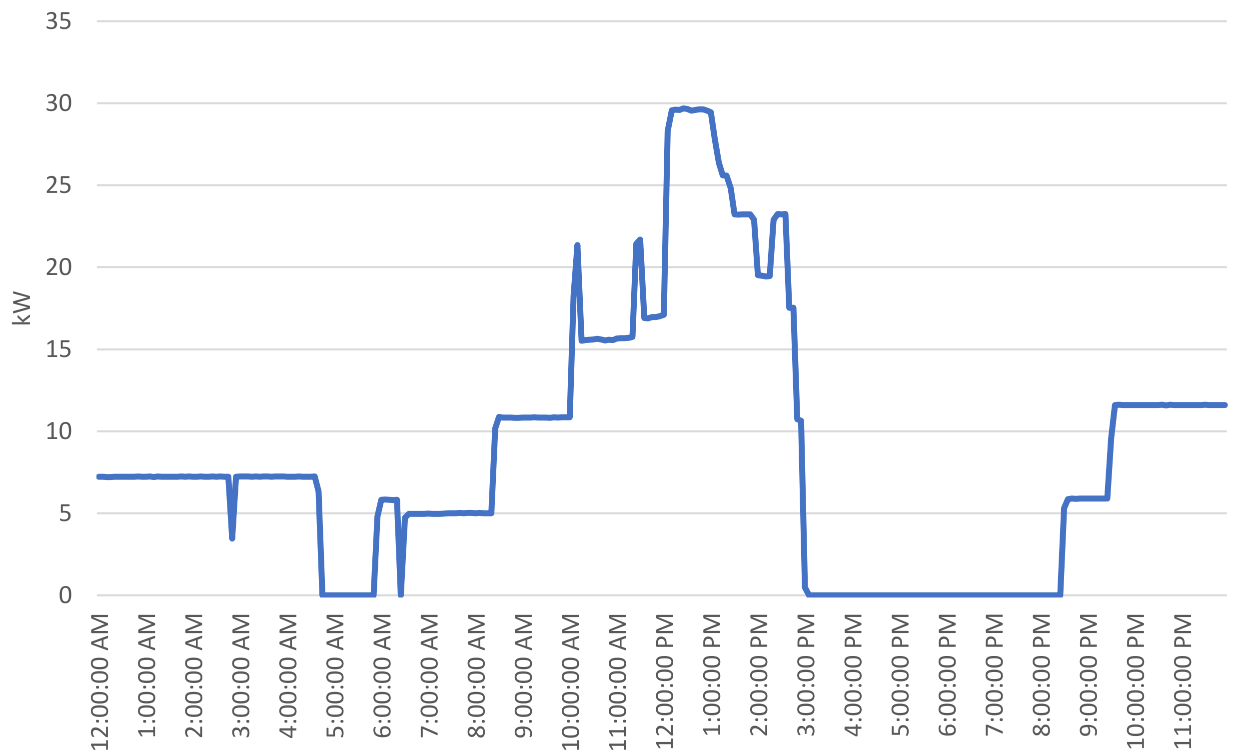
In addition to the fixed time schedule charging programs, AGL also ran non-scheduled ad-hoc charging control events during hot weather in January and February 2022.

Four of these were at the request of the United Energy/Citipower/Powercor distribution network businesses (hereinafter referred to as UE) as part of a desktop test of a possible network pricing model for EV charging. AGL and UE established a protocol whereby UE would advise a requirement for a charging control event by email the day prior. AGL would confirm receipt of this and program it into the aggregation system for execution the following day for customers in the UE area. The aggregation system was designed to include a DNSP identifier on each customer record so chargers in individual DNSP areas could be dispatched as a group.

As the event times requested by UE of 3:00pm to 7:00pm NEM time largely overlapped with the charging schedule AGL already had in place, it was only necessary to bring the start time of charging suppression forward by 1.5 hours to meet UE's requirements. This was achieved by programming a separate 1.5 hour period of charging suppression into the system immediately before the existing fixed-time schedule for the relevant customers. The finish time of 8:30pm remained the same as AGL's schedule.

A fifth ad-hoc charging control event was run by AGL on 1 February 2022. This was a day when AEMO activated the Reliability and Emergency Reserve Trader (RERT) program in Queensland due to hot weather and high system demand in both Queensland and NSW. Although the chargers were not part of the RERT program, wholesale prices were expected to be high during this period and AGL supressed charging on the chargers in Queensland and NSW an hour earlier than the routine charge control schedule.

All of these ad-hoc charging control events worked successfully to reduce the charging load in the same manner demonstrated in the scheduled charging program. Most of these events were 5½ hours, the longest single intervals of charging suppression tested during the trial. Although there were messages sent to the affected trial participants alerting them to these special events, there was no increase in opt-outs and the events went largely un-noticed. In the graph of the 14 February event below, there is a peak of charging around midday which may be a result of some customers preparing for the later event.



Charge suppression event for United Energy/Citipower/Powercor, 3:00pm to 8:30pm NEM time, 14 February 2022.

3.3.7. Opt-out rates are very low

Customer research undertaken before and during the trial by AGL indicated that customers are willing to have their charging controlled provided they can opt out of the control process at times when they simply must have their car charged. Intuitively, this makes sense – vehicles are purchased for transport purposes, and there are times when, to fulfill a transport requirement, the car may need to be charged at a time that's inconvenient for the electricity grid.

If everyone in Australia owned an EV and if they all wanted to charge them at times inconvenient for the grid, this would present a problem; however, if only a small percentage of drivers needed to charge their car at these times, this would be significantly less of an issue.

Recognising that the ability to opt-out of charging control events was an essential requirement from the customer's perspective, AGL built the trial infrastructure to include this functionality together with the ability to measure how often it was used. This was achieved by including an opt-out function in the trial app that allowed a customer to withdraw from a charging control event that was about to happen or was already underway.

Analysis of the trial data shows that the opt-out functionality is used very little and its impact on the effectiveness of controlled charging is quite small.

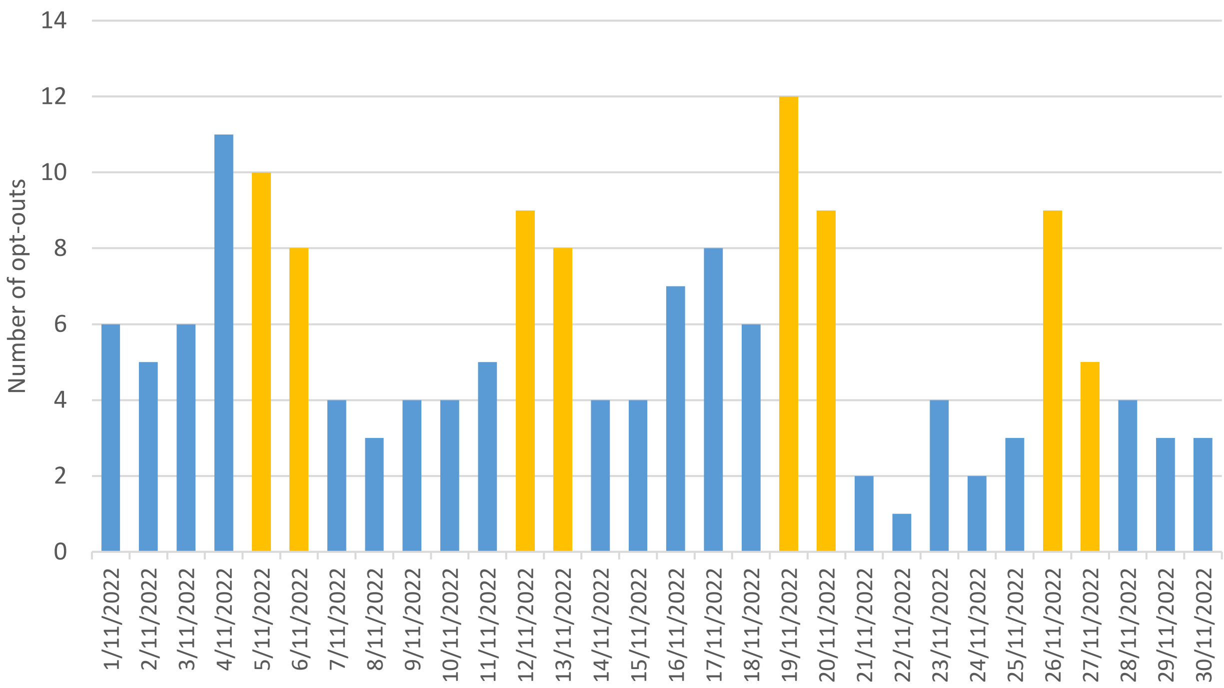
The maximum number of opt-outs per day during the period the first controlled charging schedule operated was three, and this only occurred six times. This represents about 2% of the total population of chargers. The average opt-out rate was one per day, less than 1% of chargers.

The opt-outs come from a mix of different chargers; it wasn't the same charger opting out day after day. This suggests that the opt-out functionality was used as intended; that is, used by customers who genuinely believe they needed occasional additional charging for their car, rather than individuals opting out every day whether they needed to or not.

The second charging schedule commenced in mid-June 2022 and introduced suppression of charging during the morning peak as well as the evening peak, doubling the total time charging was supressed to eight hours per day. This resulted in a small up-tick in opt-out behaviour.

Under the new charging schedule, the maximum number of daily opt-outs was six, although this only occurred once. Six opt-outs represents around 4% of chargers. Opt-outs during the rest of the rest of the time this schedule operated averaged two per day.

The third charging schedule, which increased charging suppression to nine hours a day, seven days a week, resulted in a noticeable up-tick in opt-out behaviour, but largely on weekends.



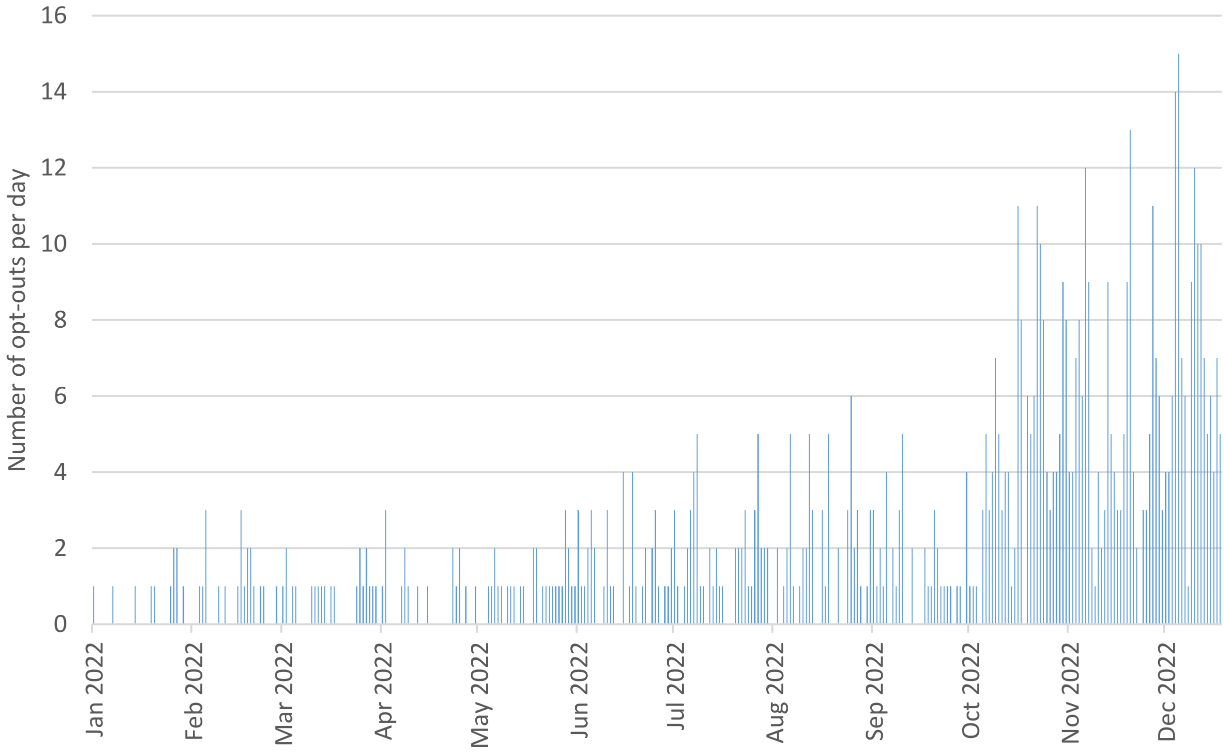
Number of opt-outs per day during November 2022, weekends shown in yellow.

This suggests that drivers were particularly concerned about a potential lack of charging on weekends. There is also a slightly higher rate of opt-outs overall, suggesting that nine hours of charging suppression was starting to test the limits of what drivers would accept without actively intervening.

Nevertheless, even with the increase in opt-outs under the more restrictive charging schedule, opt-outs overall remained low. The highest number of daily opt-outs recorded during the trial – fifteen, about 10% of chargers – was on Sunday 18 December 2022 whilst people were preparing for Christmas. The average number of daily opt-outs for period schedule three operated was six.

The average number of daily opt-outs over the entire 12 month trial was three.

These results suggest that the benefit of having an opt-out capability, ie, the acceptance of controlled charging by drivers, far outweighs the drawback of slightly reduced charging suppression during charging control events.



Daily opt-outs across the full trial. The effect of the three different charging schedules on opt-outs can be seen, with opt-outs increasing as the supressed charging periods became longer.

Opt-out behaviour was similar for the ad-hoc charging control events executed during the trial. For the five ad-hoc charging control events held in January and February 2022 where the controlled period of charging commenced earlier in the afternoon (see section 3.3.2), opt-outs were negligible at either zero or one on the days in question, suggesting customers were either unconcerned about the longer suppressed charging on those days, or understood the reasons for it and were happy to participate.

3.3.8. Very few drivers charge their car daily

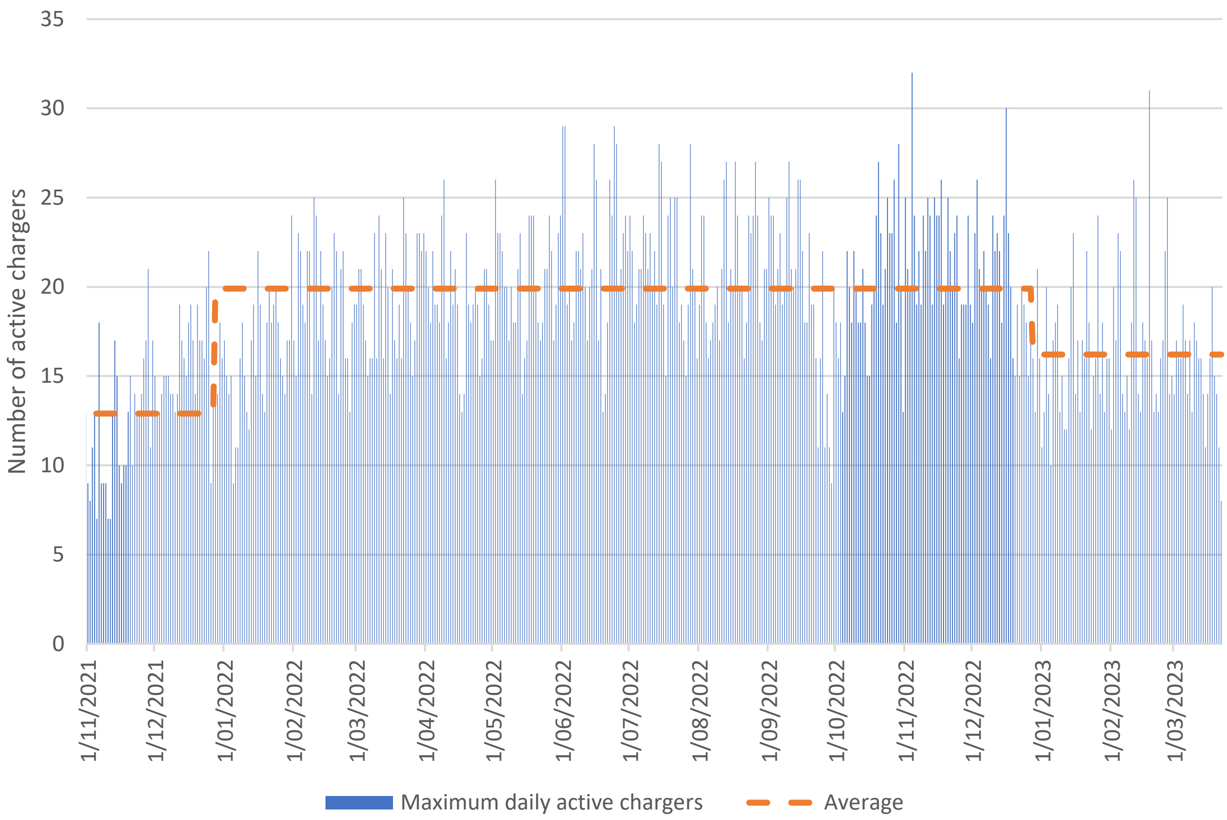
The vast majority of drivers do not charge every day and the number of chargers operating concurrently is relatively low. During the trial, the maximum number of chargers recorded operating at the one time was 32 (20% of the fleet[9]) and that only occurred once, with the number more typically being less than 25 (16%).

Across the full year of the controlled charging trial, the average daily maximum number of chargers in use concurrently was 19.9, corresponding to 12% of the fleet.

During the baseline periods before and after the controlled charging trial, when unconstrained charging behaviour was being measured, the number of concurrent chargers in use was even lower, suggesting that controlled charging was successful in moving vehicle charging to be more co-incident.

[9] Refer to section 3.3.10 for discussion on the overall population of chargers used in these calculations.

In the baseline period before the trial (late 2021 – possibly covid affected) the average daily maximum number of chargers operating concurrently was 12.9 (8% of the fleet). In the baseline period after the trial (early 2022), the average daily maximum number of chargers operating concurrently was 16.2 (10% of the fleet).



Maximum number of concurrently active chargers by day for baseline and controlled charging periods

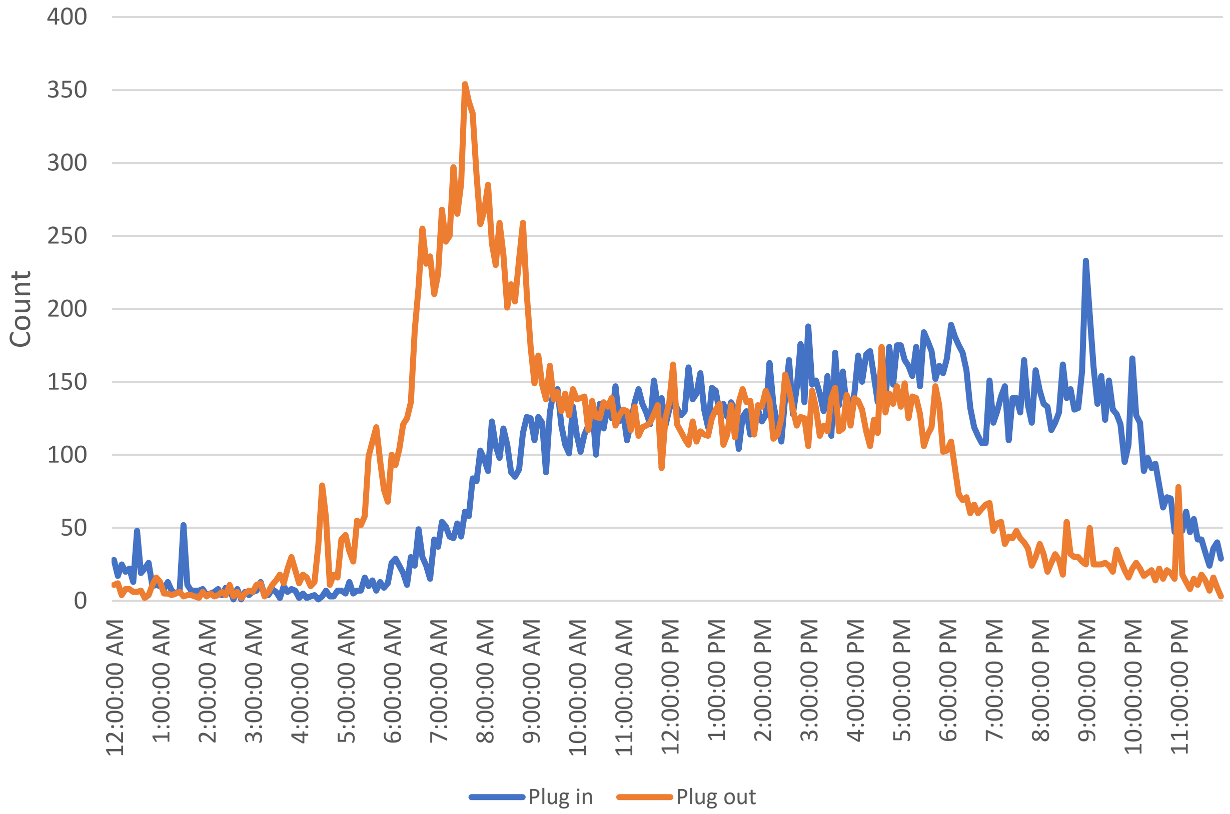
During customer research of trial participants undertaken by AGL, we asked customers how often they charged their car. 16% indicated that they charge daily, with 50% of people saying they charged every few days and 12% saying they charged weekly. At least at an order of magnitude level, this research appears to be confirmed by the quantitative data.

These findings suggest that concerns by the electricity supply industry that everyone would charge their vehicles at once are unlikely to be realised, and the impact of residential vehicle charging on the grid may be quite minimal until there are significantly more EVs are on the road. This appears to be borne out by overseas experience, where countries with a relatively high penetration of EVs (eg Norway, now with about 20% of vehicles on the road) have not reported major problems with the electricity grid.

3.3.9. Plug-in and plug-out behaviour

Knowledge of plug-in and plug-out behaviour is useful in assessing the value of EV charging load as a distributed energy resource. A vehicle that isn't plugged in is unable to provide any value to the grid, particularly in the case of V2G where discharging to provide, for example, frequency services, requires the car to be present, plugged in and sufficiently charged.

The following graph shows the total count of plug-ins and plug-outs for the entire 18 month period of the project (baseline and controlled charging periods – there was no discernible difference in behaviour between the two):



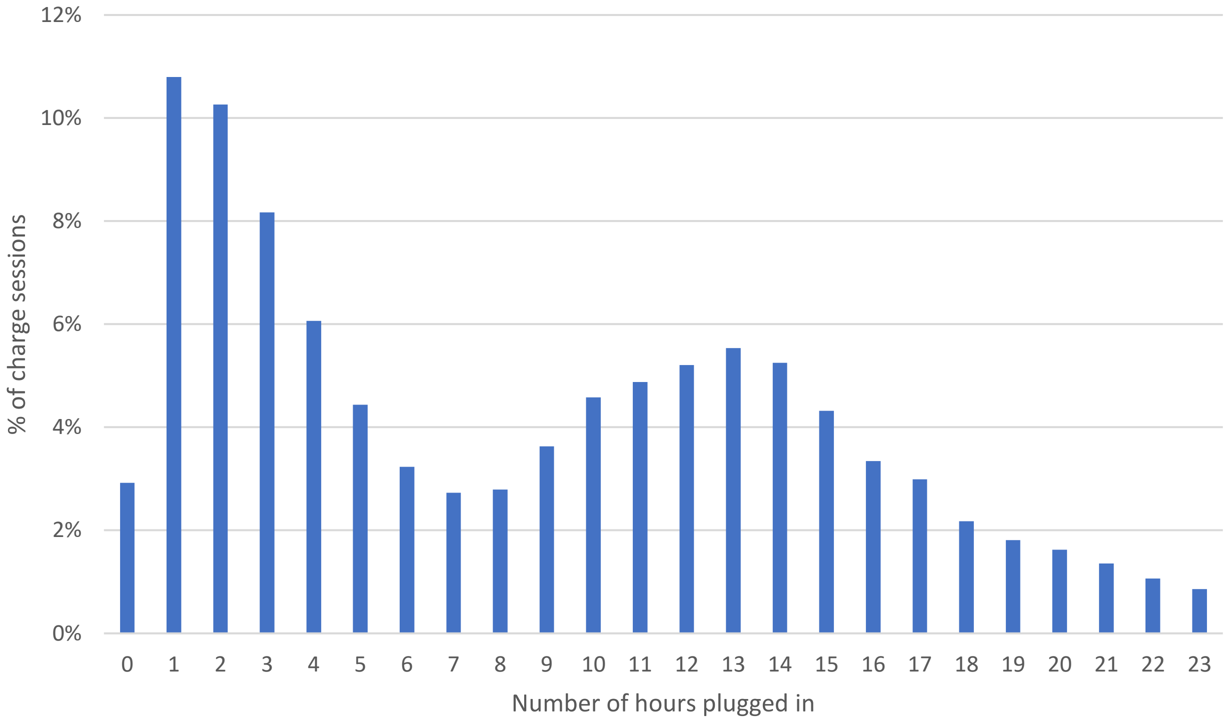
Total plug-in and plug-out count across the day for the trial

- From almost zero overnight, plug-ins increase from 6:00am to 10:00am and then remain relatively flat for the rest of the day, with a small increase in the late afternoon and early evening. There are small spikes at 9:00pm and 10:00pm as drivers manually plug their car in to catch the low rate of time-of-use tariffs, but plug-ins drop quickly after 10:00pm.
- From almost zero overnight, there is a steep increase in plug-outs from about 6:00am, peaking at around 7:00am and reducing at 9:00am. Plug-outs are flat for the rest of the day until 6:00pm, and then drop over the course of the evening.

One of the important lessons from this data is the diverse nature of the behaviour. There are lots of plug-ins and plug-outs happening continually across the day, with only the morning plug-out being particularly notable as confluent behaviour (alongside the expected low level of plugging activity overnight).

As with the charging load data, there is no evidence of large numbers of drivers concurrently plugging in their vehicles in the late afternoon or early evening.

Related to the plug-in and plug-out times is the length of time that vehicles remain connected after they've been plugged in.



Percentage of charge sessions vs number of hours plugged in

Many plug-in sessions were quite short, with 32% being three hours or less, and 51% being eight hours or less. Only 3% of sessions were longer than 20 hours. The average length of the plug-in sessions across the trial was 8½ hours.

For standard one-way EV charging, the kW demand curves probably give a better view of the DER potential of this load than the plug-in time. However, the plug-in time would be particularly valuable in assessing the potential value of V2G, as V2G relies on the vehicle being plugged in reasonably consistently in order to provide the opportunity to move energy back from the vehicle to the grid. The longer it's plugged in, the greater the potential value of V2G.

3.3.10. Not all chargers communicate all the time

At any one time, around 20% of the installed smart chargers were not returning charging data to the software platform. This was sometimes an intermittent problem, and the charger would come back online without any further action, or it was a permanent failure requiring action to fix.

There was not a single mode of failure causing this issue; there are a variety of different causes without a single reason dominating. However, 20% of chargers is a disappointingly large proportion to be not communicating and this is an area that will need further work before a full-scale rollout.

For the trial, AGL elected to use the customer's internet service to communicate with the chargers. This avoided the problems that can occur with cellular communications when there is no cellular coverage or the device is in a fringe reception area, and is also a lower-cost approach as there is no carrier access fee involved. The data impact of a charger on the customer's internet service is negligible.

The two methods used to connect the charger to the customer's internet were:

- An ethernet cable between the customer router and the charger. This was the preferred method and was used wherever possible.
- Where a wired connection was not possible due to excessive cable length or access problems, an internet-over-powerline device was used.

Wi-Fi communication was not generally used in the trial, due to previous experience with other residential distributed energy devices connected via this method. There are several known failure modes with Wi-Fi, including customers changing passwords or other Wi-Fi parameters, which can result in disconnection of the device.

In the trial, the reasons identified for non-communicating chargers include:

- Intermittent communications connection, root cause generally unknown.
- The customer turned off the charger at the wall mounted isolator. This was an ongoing issue with a small number of customers concerned about the weather proofness of the charger or its standby energy use. These customers turned the charger back on when they needed to use it, so the charging data is recorded, but the charger was offline most of the time.
- The charger needed to be power cycled to reboot.
- Internet-over-powerline devices failed, or were removed or tampered with.
- The ethernet cable was disconnected from the router or charger or the cable termination failed.
- In Queensland, the DSNP load control scheme repeatedly disconnected the charger from supply.
- The charger hardware failed and needed to be replaced. This was quite rare, affecting less than 5% of chargers installed.

The findings arising from this were:

- Using the customer's internet service always carries a risk that the customer may intervene, either deliberately or by accident, and prevent the charger communicating.

- Smart charging technology is not perfect yet.
- A charger that is turned off will not communicate.

To mitigate at least some of these issues, a preferable communications approach may be to use the cellular network where the signal strength is good, using wired ethernet only when this is not the case.

Furthermore, a system that encourages the customer to manage the ongoing operation of their own charger would mean that these problems could be dealt with early and at low cost, rather than requiring calls to customer support staff. There could perhaps be enhancements to the app that would further engage the customers to do this themselves, as a charger that is not communicating is not able to be monitored or controlled by the customer either.

Unrelated to the reliability of communications or whether the charger is on or off supply, there are other reasons why charging data may not be received from chargers that are otherwise working. These include:

- The customer is doing most or all of their charging at a location other than home.
- The customer is charging from a standard power point and not using the smart charger.
- The customer no longer has an EV.

There were a small number of trial customers in each of these categories.

There were also cases where the customer had problems charging their car despite everything on the charger side being confirmed as working correctly. These may be due to problems with the car itself, or the charging control system in the car being programmed in a way that the customer is not familiar with. These issues can be difficult for support staff to diagnose without specialist knowledge of the vehicle.

Whilst charging from a power point is an easy way for customers to get around charger control (at the expense of a lower charging speed), there was no evidence that this was systematic behaviour in the trial. There were a small number of customers who did it from time to time when there was an insurmountable problem with their charger, until the problem was resolved. In practice customers used the opt-out function if they needed to charge during a period that charging was supressed.

There was a 10% loss of customers throughout the trial for reasons including the customer moving house, the customer changing retailer, the customer's personal circumstances changing or the customer just wished to leave the trial. This also reduced the number of chargers returning data. These issues are an everyday occurrence with customer-owned distributed energy devices and are not unique to EV charging.

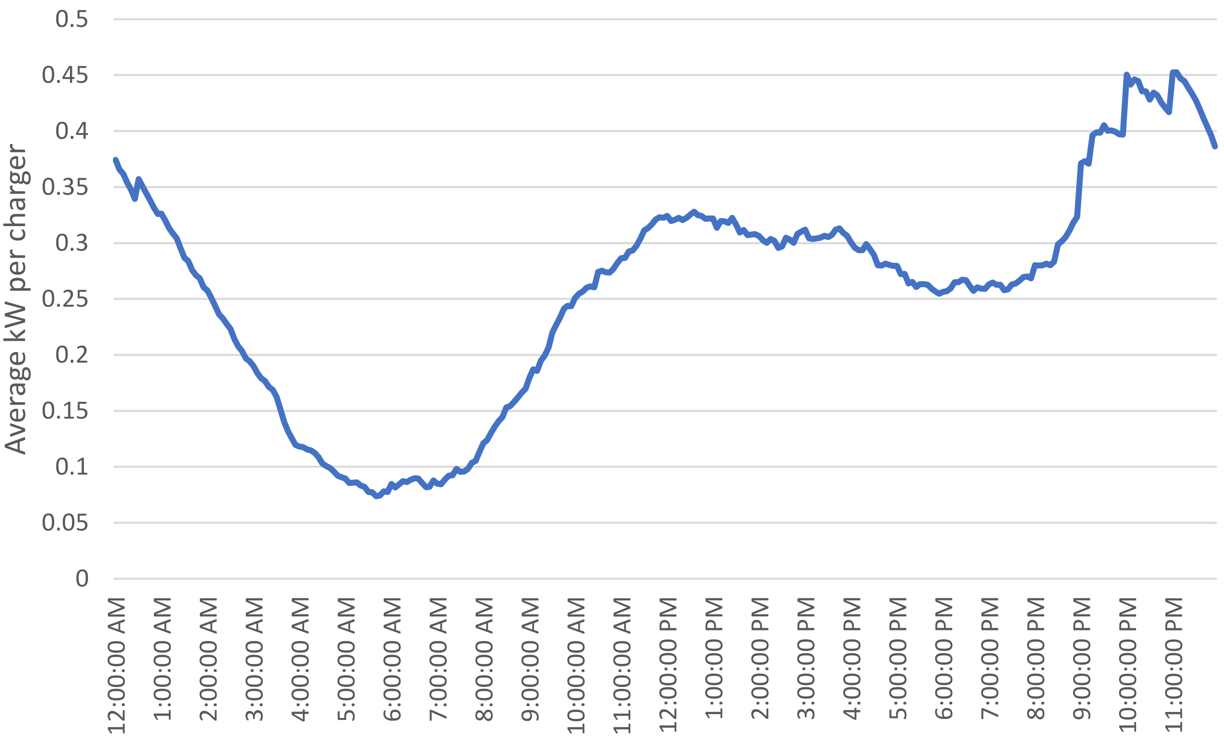
3.3.11. Per-charger demand

The average charger load has been calculated for the baseline and controlled charging periods of the trial. Whilst it would be possible to analyse this data many ways and get slightly different results, broadly speaking the data shows the average load per charger to be quite small, and well below the nameplate rating of the chargers.

Several factors are likely to have influenced this:

- Very few customers charge daily.
- Customers plug in at diverse times across the day.
- Customer vehicle usage varies, so charging time varies.
- Vehicle charging systems modulate charging in different ways.
- A significant percentage of chargers had their maximum capacity reduced by household wiring limitations or network connection rules.
- Some vehicle charging is done at locations other than home (see section 4.1.3).

The trial has revealed that there is a lot of diversity in home vehicle charging. In this respect the charging load is quite different to some other residential loads, for example air conditioning, where there is a significant convergence of usage in the afternoons of very hot days, or cooking, where most of the load occurs over a couple of hours in the early evening.



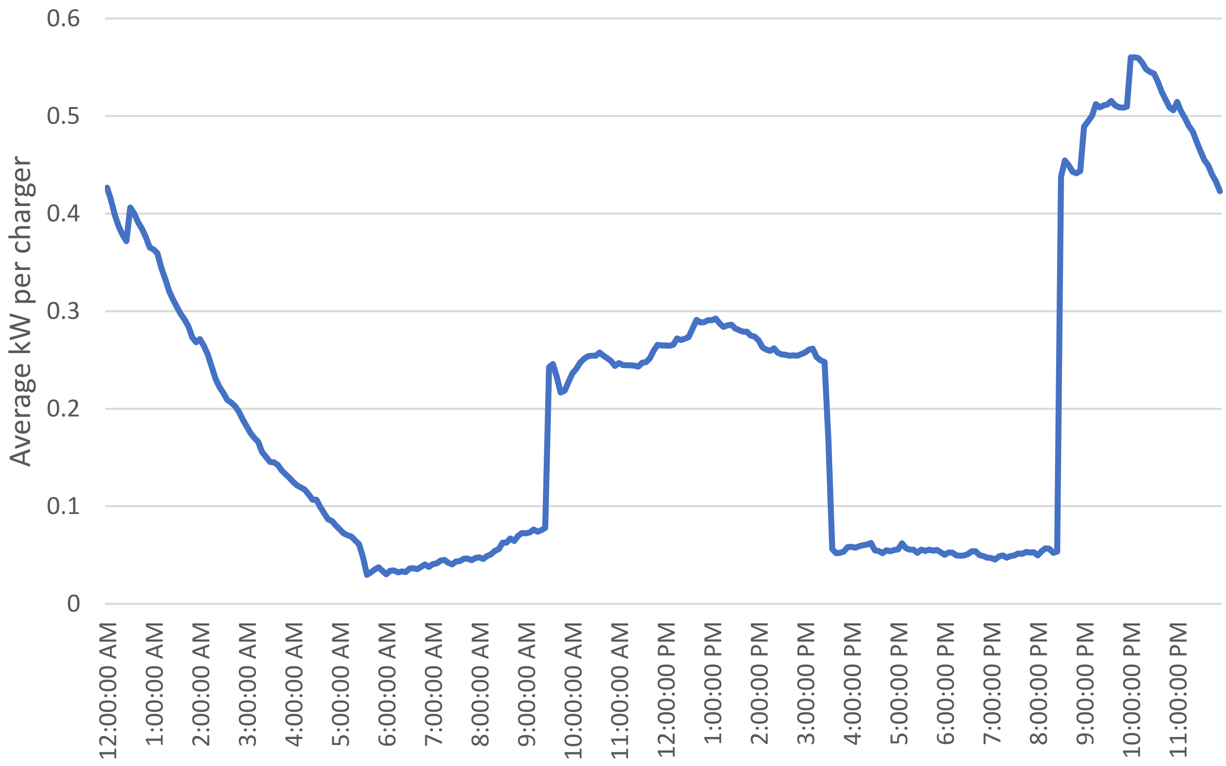
Baseline average daily kW demand per charger

For the baseline period, the average kW demand per charger peaked at 0.45kW, driven by the TOU peak in the late evening as drivers self-control their charging. The size of this TOU peak is dependent on the percentage of TOU customers in the sample – the higher the percentage of TOU customers, the higher the peak. In the trial, 34% of customers had a TOU tariff.

Fortunately, this peak occurs well after the early evening system peak, however it may coincide with controlled hot water peaks in some states. The trial results suggest that this peak is quite steerable, however, and its timing could be modified with changes to TOU times if necessary.

The baseline average charger load present during the early evening peak is around 0.26kW. This may be relevant for after-diversity maximum demand calculations for residential load, as this is co-incident with early evening peak loads from other household appliances.

By definition, centrally controlling EV charging reduces the diversity of the charging load, therefore increases the maximum demand. Under the most aggressive charging schedule trialled, schedule 3, the average maximum demand per charger was 0.55kW in the late evening, 22% higher than the baseline case. However, the average charger load during the early evening peak was a negligible 50W, as the charging schedule was successful in removing almost all charging from this period.



Controlled charging average daily kW demand per charger (schedule 3)

3.3.12. The value of smart charging

AGL has estimated the value of smart charging as a distributed energy resource using the data collected from the trial. The assessment is indicative for the following reasons:

1) Averages are used throughout, however in reality these are a mix of very high and very low values. If the loads don't respond consistently on days when the NEM price spreads are largest,

this will affect the net benefit. There can also be significant variations in NEM prices between states. Individual chargers that are more heavily or lightly used than average will also have differing benefits.

2) NEM prices and price spreads fluctuate significantly from month to month and year to year for a variety of reasons. The calculation uses historical data which may not represent future value.

3) The calculation is based on NEM spot prices, but in reality the cost base of market participants such as retailers is formed by a combination of financial and physical hedges together with spot prices. The makeup of this portfolio varies between participants, therefore the value will vary from participant to participant.

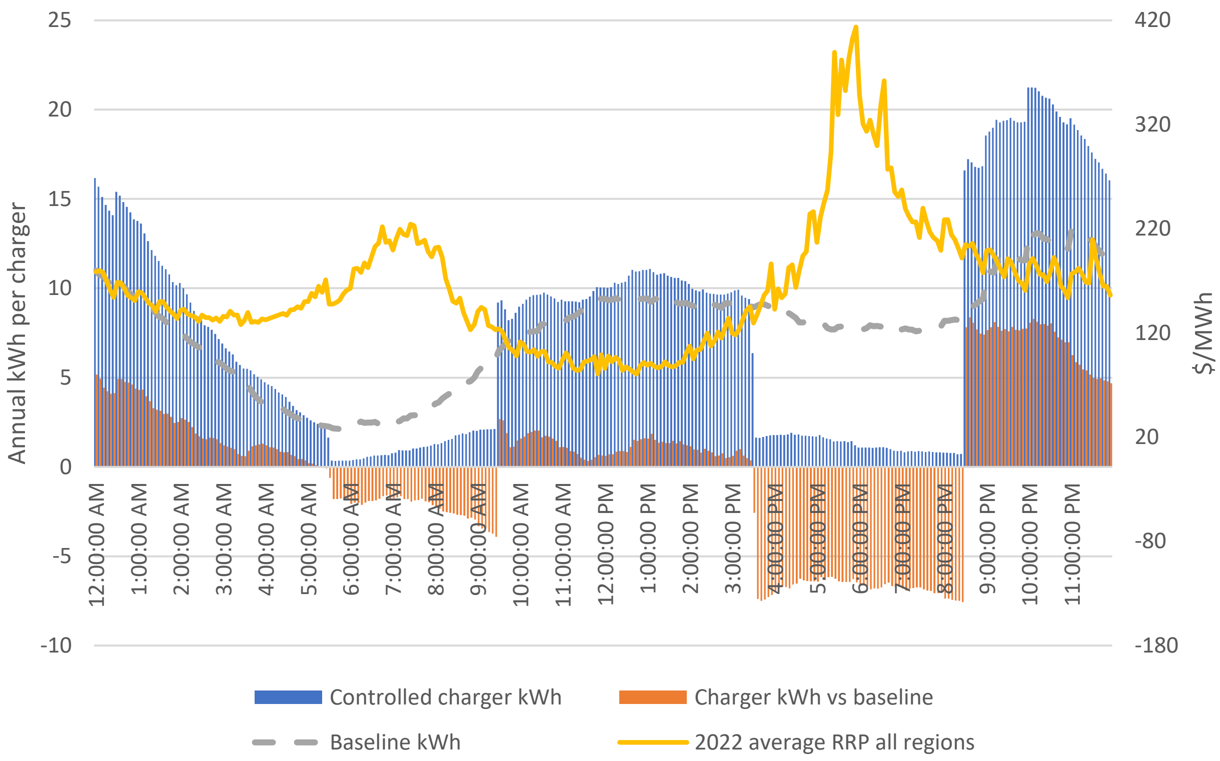
This calculation concentrates on wholesale market value. There are several other potential value streams that may result from control of charging, but these have not been included in the evaluation:

1) Network value definitely exists and the effectiveness of charging orchestration in responding to test network events is covered in section 3.3.6, however the value tends to be specific to certain areas in certain periods of time and is difficult to value in a general sense. We expect that, taken across the full population, this benefit would be relatively small compared to the wholesale value. Nevertheless, the benefit can be significant for small groups of chargers in specific network areas.

2) Emergency reserve response such as RERT could also generate value from orchestrated charging. However, if a charging schedule similar to those in the trial was implemented in practice, the majority of RERT events would coincide with periods when charging was suppressed anyway, and the additional value would be minimal (except perhaps to reduce the likelihood of the RERT events occurring in the first place).

3) Lastly, there is potential value in EV charging orchestration for contingency frequency response (raise frequency if charging is already on, lower frequency if charging is off), however this relies upon frequency response control functionality being built into chargers themselves. We are not aware of any charger on the market at present, either in Australia or overseas, that has this functionality, and how well it would work in tandem with the various in-vehicle charging control systems is unclear. This value has therefore been excluded.

For the value analysis we have used the most aggressive charging schedule from the trial, schedule 3, annualised across the full year.



Annual 5-minute kWh per charger for schedule 3, and kWh difference between schedule and baseline, plotted against the average NEM regional reference price for all NEM regions in 2022.

It's clear from the graph that the charging schedule was highly effective in moving load away from the morning and evening NEM-wide reference price peaks, particularly in the evening where the benefit is quite dramatic.

Multiplying the changes in annual kWh consumption (in 5-minute intervals) resulting from controlled charging against the average reference price across the day yields an annual wholesale market benefit of $33 per charger for the 2022 calendar year under schedule 3.

The net benefit that could be achieved in practice would differ from this for the following reasons:

1) The wholesale benefit doesn't take into account costs such as the cost of installing/operating/maintaining the system, the cost of network access if cellular communication is used, customer support and issue resolution, and other overhead costs.

2) The hedging strategies of market participants will generally diminish the gross margin benefit as most market participants are not wholly exposed to spot prices.

3) NEM pricing in 2022 was affected by the conflict in Ukraine, leading to elevated gas and coal costs and suspension of the market between 15 and 24 June. To what extent 2022 is typical of future years remains to be seen.

It should be noted that, based on what we have seen of charging behaviour during the trial, much of this benefit may also be able to be achieved with an appropriately designed TOU tariff. This would also have the benefit of not incurring the costs in (1) above.

3.3.13. Costs

It can often be challenging to draw conclusions about long-term large-scale costs from a small-scale trial, however the operating costs of the trial can give some indication of the potential order-of-magnitude costs of running large scale charger orchestration.

Excluding the cost of software development and the management of the trial itself, the key costs for the smart charger stream were:

Item	Average cost per charger
Charger supply and installation	$3,142
Software platform operating cost	$149/year
Customer support	$365/year

These costs are clearly much higher than the benefit identified in section 3.3.12, however the ongoing operating costs would likely be lower in the case of a large scale rollout.

Charger supply and installation

At $2,050 each, two-thirds of the charger supply and installation cost was the cost of the charger itself. The cost of smart chargers with similar functionality to the trial units has reduced a little since the trial began, and this can be expected to continue as production volumes increase, the technology develops further and more competition enters the market. We expect the cost of most smart chargers to be around $1,000 - $1,200 within the next two to three years.

At $1,092, the average cost of retrofitting a charger to an existing house during the trial was significant, particularly since the trial selection process deliberately excluded properties that would have had much higher installation costs than allowed for in the project budget. These included properties where trenching was necessary to install a charger in a detached garage and properties where switchboard or wiring upgrades were required.

As the trial selection process also excluded multi-unit properties with an owner's corporation, the costs for these remain unclear.

Installation cost is predominantly the cost of electrician labour plus basic electrical items such as cable, circuit breakers and isolators. These costs are unlikely to reduce over time. The installation cost could be lower, however, for chargers installed as part of a new home construction.

During the trial, the cost of the chargers and installation was paid for by ARENA funding and was completely free for most of the participants. In some cases, where an installation was outside the scope of a “standard” installation set by the trial budget, the participants were asked to provide a contribution to cover the difference in costs, but this was generally small relative to the overall cost of the work.

Software platform operating cost

We believe the per-charger cost of operating the software platform was higher in the trial than would be the case in a large-scale implementation, however at this stage we do not have enough information to estimate what the cost would be in a large-scale rollout.

Customer support

During the trial, customer support was achieved with specially trained customer service managers responding to phone calls and email requests from trial participants having problems with, or questions about, their charging. Whilst, to some extent, the cost of customer support in the trial reflects the newness of the technology and the unfamiliarity of many customers with vehicle charging issues in general, the level of support required for vehicle charging management should not be underestimated. While most other utility-controlled loads like hot water operate without the customer being aware of, or interested in, what’s going on, what happens with their vehicle charging is front-and-centre of their attention and any issues they perceive to have occurred require a high level of timely customer support.

This is further complicated by the fact that what may appear to be charging management issues are sometimes caused by the behaviour of the vehicle itself, and some customers are unfamiliar with the way their vehicle operates and its more advanced features. It’s difficult for customer support personnel to be conversant with the operation of all vehicles on the market and provide detailed support in many of these cases.

4. Vehicle API Technology Trial

An Application Program Interface (API) is a software interface that allows computer systems to communicate with each other using an interface specification designed specifically for the task at hand. Modern APIs are implemented using purpose-designed technology frameworks that inherently contain a high level of security and are well supported and understood across the information technology community.

In the context of electric vehicles, an API allows a third party, such as an electricity supply company or aggregator, to communicate with vehicles via the vehicle manufacturer's back-office software platform and vehicle telemetry system. Information such as charging and battery status data can be read from the vehicle and charging control commands can be sent to the vehicle for execution.

Importantly, the vehicle API allows the remote control of vehicle charging without the use of a smart charger, and the primary aim of AGL's trial was to test how this works in practice.

AGL's trial of vehicle API charging control comprised 100 vehicles across two vehicle telemetry platform suppliers, Flexcharging (USA) and ev.energy (UK). Due to the limited support in Australia of vehicle API functionality in EVs currently on the market, all the vehicles in the trial were Tesla, the only manufacturer who provided this support at the time the trial commenced.

The objectives of the vehicle API technology trial were to:

- understand how the technology works
- understand the capabilities of the technology
- see how customers respond to the technology
- establish what issues may need to be addressed for future implementation.

Running the technology trial alongside the more mature smart charger trial provided a useful counterpoint to understanding how the different technologies could be used to address the same problem.

AGL implemented the same charging schedules with vehicle API customers as were tested in the main smart charging trial stream, largely to understand if it was possible to do this. However, although the data from the vehicle API platforms was ingested into AGL's NEO database, it was not integrated with the smart charger data for the following reasons:

- The data available from the various platforms, and the resolution of that data, was different and difficult to integrate in a meaningful way.
- In addition to the load shaping from the static charging schedules implemented by AGL, both vehicle API platform providers use proprietary algorithms to try to optimise the charging of the car within the time windows available. This made comparison between the vehicle API platforms and the smart charger platform problematic as the exact operation of these algorithms was not transparent and there was no similar optimisation undertaken in the smart charger stream.

Vehicle API platforms can determine where the vehicle is being charged from the geographic location data provided by the vehicle. In the context of charging orchestration, this was used to discriminate between home and away-from-home charging and ensured that only home charging was controlled; once the driver moved away from home they were free to charge the vehicle at any time.

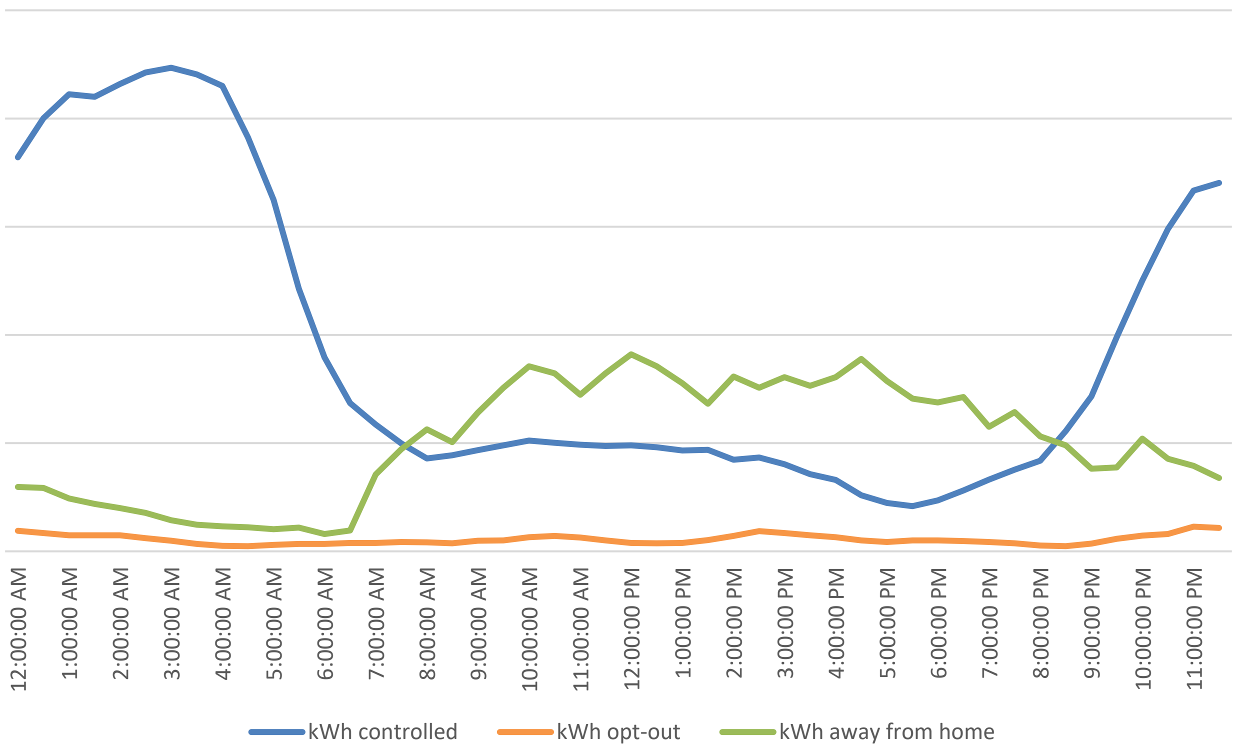
It should be noted that, as the vehicle API trial was limited to Tesla vehicles, some of the issues observed may relate to the way Tesla vehicles in particular respond to events. This may or may not be representative of the behaviour of other vehicles, or even Teslas in the longer term.

It's also worth noting that Tesla have, from time to time, provided certain incentives to their drivers, such as free charging at Tesla Superchargers, which may have influenced their behaviour compared to drivers of other EVs. This may also have affected the trial results.

4.1. Trial Outcomes – Vehicle API Technology Trial

4.1.1. Vehicle API control is effective in moving charging away from peak times

The vehicle API stream was similarly effective as the smart charger stream in moving charging load away from peak demand periods.



Typical weekday daily load shape for vehicle API charging (schedule 2, ev.energy platform)

One key difference between the two trial streams was that the vehicle API controlled charging did not exhibit the same late evening peak as the smart charger group when charging was resumed after suppression in the early evening. This is because both vehicle API platforms employ a “ready-by time” algorithm to push charging as late as possible into the night. These algorithms use a time entered by the driver for when charging is to be complete, together with the state-of-charge reading from the vehicle, to calculate the time charging should commence in order to reach the desired charge by the desired time.

The “ready-by time” algorithms were quite effective in managing charging overnight, however they were less effective when consumption of solar generated energy was desired during the day. They also introduced a degree of uncertainty in the minds of drivers about what was actually happening with their vehicle, with some drivers reporting surprise that the vehicle didn’t start to charge when they plugged it in at various times during the day. It’s also a far more complicated concept for customer service staff to explain to customers, compared to the simple “charging will be off between these times” model used in the smart charger stream.

Opt-outs from controlled charging were as low in the vehicle API group as they were in the smart charger stream.

4.1.2. Visibility of vehicle battery and charging data

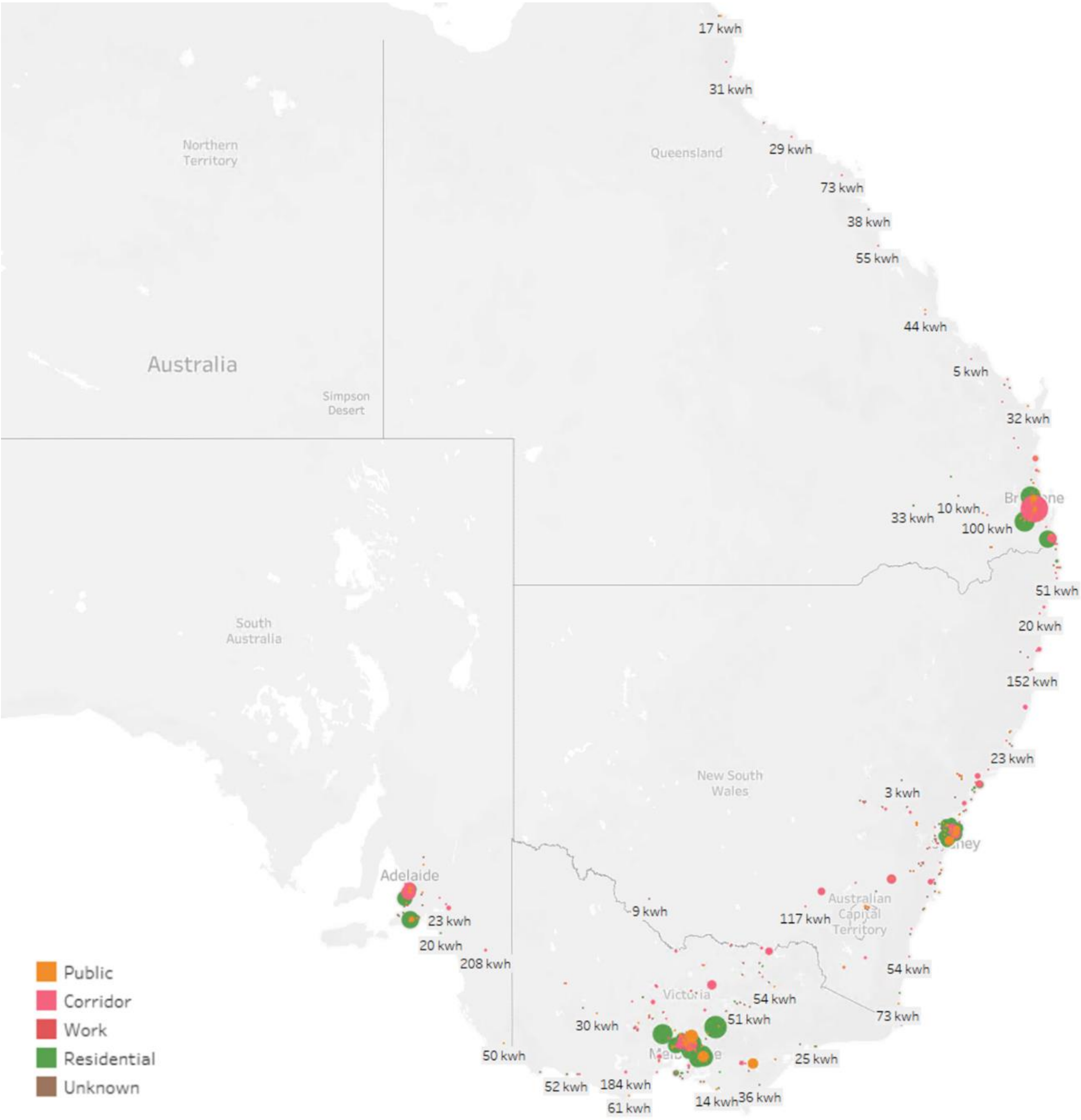
Vehicle API is currently the only technology that can determine vehicle battery state-of-charge information in a home charging setting. AC home chargers, such as the chargers used in the smart charging stream of the trial, don’t provide this information[10].

State-of-charge is necessary to accurately predict how much charge a vehicle may need in a particular charge cycle. It opens the possibility that the commencement of charging may be deferred to the latest possible time with the vehicle still reaching the desired level of charge by a time nominated by the driver, for example 7:00am. Both vehicle API platforms being trialled undertook this type of optimisation.

The geographic location data obtained from the vehicle also provides visibility as to where that charging is happening. Other than being used to discriminate between home and away-from-home charging for control purposes, this data has the potential to provide valuable usage information for the planning of charging networks, or increase the accuracy of predictions regarding the amount of home charging necessary for a particular vehicle on a particular day.

The graph in section 4.1.1 above also includes data for a typical day of away-from-home charging for the trial group. As would be expected, away-from-home charging generally commences from about 7:00am and reduces after 10:00pm, with only a small amount occurring overnight.

[10] We understand that state-of-charge is being considered for future versions of the standards governing communications between the vehicle, charger and back-office platform.



Charging location visualisation from the Flexcharging platform

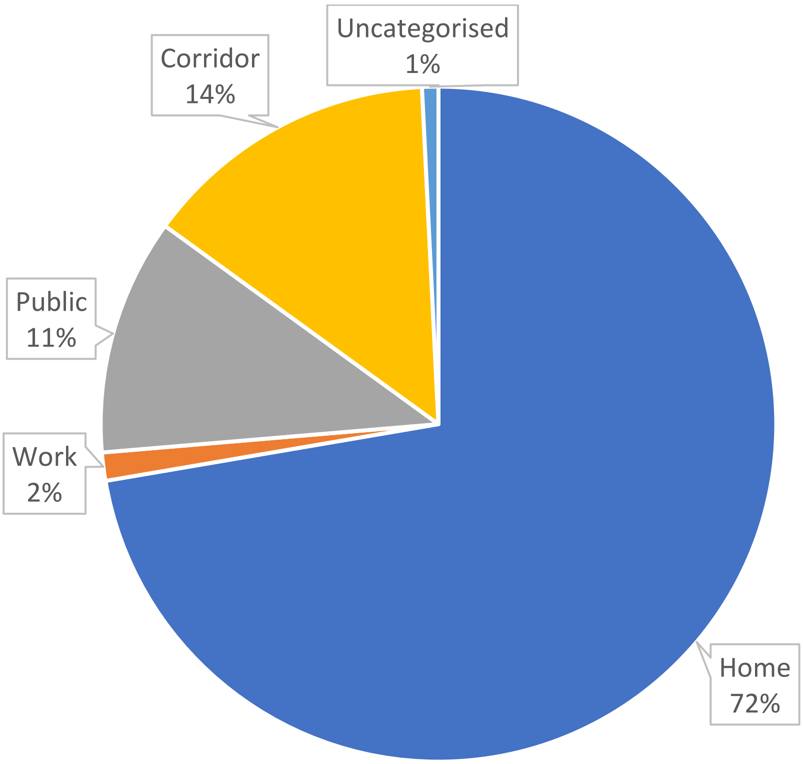
4.1.3. Home charging is about 70% of overall charging

In the vehicle API model, charging location can be determined from the GIS coordinates of the vehicle while it's charging. Trial participants nominate their home location using the app; only charging at home is controlled.

Some earlier studies undertaken on EV charging suggested drivers do around 80% to 90% of their charging at home. The data from our vehicle API trial suggests home charging represents about 70% of charging by energy consumed, at least for the trial Teslas. It's possible that this lower figure may be due to the increased number of public charging facilities established in recent years, the free charging available at some of these stations, or the possibility that a Tesla owner will use a Supercharger station more frequently if they are one of the small number of drivers with a free charging plan.

The Flexcharging platform provided quite detailed information about where charging occurred and the type of charging taking place. The accuracy of this data increased throughout the trial as Flexcharging worked to correctly categorise the type of charger at each location; the number of uncategorised chargers at the end of the trial was negligible at slightly under 1%.

The platform recorded a figure of 72% home charging by energy consumed for the full trial period.



Percentage of energy consumed by charging location for Flexcharging vehicles in the trial.

While the data from the ev.energy platform was not as detailed (just in-home or away from home), the home charging percentage recorded over the trial period was an almost identical 71%, giving some confidence to these figures.

4.1.4. API access to vehicle data needs to be improved

During the trial, there were multiple changes to the security system used by the Tesla software platform that manages vehicle data. This affected both Flexcharging and ev.energy drivers, who had to re-login multiple times to the platforms to re-align with the changes made by Tesla, not to mention

Flexcharging and ev.energy themselves, who had to make regular unplanned updates to their software to cope with these changes. Dealing with these issues also consumed a lot of customer support time.

This highlights a shortcoming in the current approach for data provision by vehicle manufacturers, including Tesla, where a third party wishing to obtain vehicle API data must use the customer login details. Any changes to the process customers use to log into the vehicle manufacturer's system, for example modifications to two-factor authentication, will necessitate a corresponding change to the vehicle API data platform login process. Also, any changes that the customer makes to their login details, such as a password change, will log them out of the third-party's vehicle API platform until they re-authenticate back into that platform.

A preferable approach would be for the vehicle industry to provide specific third-party APIs for parties interested in using the vehicle data, such as the electricity industry, who would then have direct access to the data once permission had been granted by the driver. This is analogous to the process that already exists in the home battery industry.

It is understood that some vehicle manufacturers are already moving in this direction. For example, BMW is one company making vehicle data available via an API to third parties for a cost, subject to the driver giving permission for third-party access[11]. This facility is currently only available in Europe and the UK, but can be expected to be offered in Australia in the future.

4.1.5. Coordination with solar

In its current form, vehicle API control of charging has only a limited capability to coordinate with rooftop solar generation. As there is no hardware installed at the home for controlling charging, it's not possible to directly measure solar generation or export on-site using current transformers and use this to directly modulate the level of charging.

There are two possibilities for future developments in this regard:

1) The use of an irradiation forecast or measurement at city or state level to determine the approximate level of solar generation from rooftop solar at the premises. Both of the trial platform suppliers have recently introduced a version of this in some markets, although it was not available to trial in Australia in time for this project. Whilst this would only be an approximation for any particular site, it may be sufficient to achieve most of the benefits.

2) Cloud integration between the solar inverter supplier's platform and the vehicle API control platform. Australian company ChargeHQ is currently offering a cloud software service that aims to do this[12]. Although this approach requires a lot of software integration, it could potentially provide more direct control of solar charging than (1) above.

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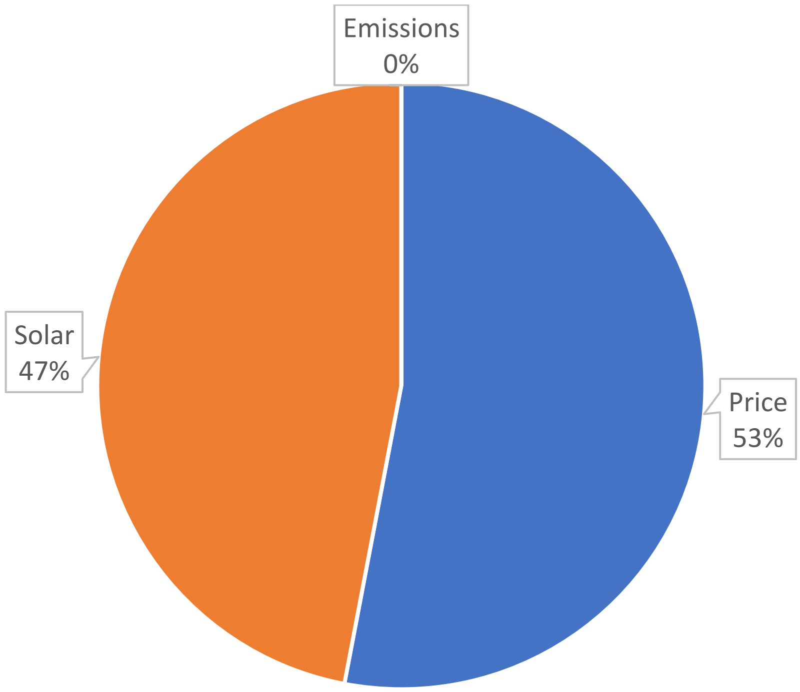
[11] https://bmw-cardata.bmwgroup.com/thirdparty/public/car-data

[12] https://chargehq.net/

4.1.6. Algorithmic charging is difficult for some customers

Both vehicle API platform suppliers use an algorithm to optimise vehicle charging against parameters entered by the customer. These allowed the customer to prioritise charging for lowest cost (based on their TOU tariff if they had one), lowest grid-level carbon dioxide emissions or maximum utilisation of solar, together with the "ready-by time" algorithm that ensured the vehicle would be fully charged by a time nominated by the driver.

Although some of these options were not fully functional in Australia during the trial, it's interesting to note the preferences of customers through the options they selected.



Flexcharging customer charging preferences

Whilst a small number of customers had chosen minimum emissions as their preferred option early in the trial, by the end of the trial all of the Flexcharging customers had selected either lowest price or solar charging as their priority. This may be reflective of the general increase in energy prices that occurred in 2022 due to the conflict in Ukraine, or it may be reflective of customer behaviour more generally. The preference for solar charging by nearly half of the participants is consistent with our customer research that showed solar charging was a strong preference amongst those customers with rooftop solar.

One issue that arose from the algorithmic approach to charging, however, was a certain amount of confusion from customers about what their vehicle was doing, when it was going to charge and why it wasn't charging when they plugged it in. There were a significant number of customer service calls about this. Although the customers could always override charging control using the opt-out functionality in the app, in many cases they didn't do this as a matter of course and tended to think there was something wrong instead.

This is an area that may require further work. The operation of the various algorithms optimising for different parameters, and what this means for charging availability, is not necessarily well understood by customers, and it isn't a simple task for customer service personnel to explain it to them. With the trial customers generally in the "innovator" and "early adopter" categories but already having problems, this may become a bigger issue as EV penetration increases and the customers involved become less technically adept.

4.1.7. Vehicles waking during communication sessions

A number of vehicle API customers reported dissatisfaction with the amount of time that their vehicle was "woken up" by communications from both of the vehicle API platforms. A small number of customers were so upset by this that they left the trial – their perception was that the energy in their vehicle battery was being wasted on communications, even though the amount of energy involved is quite small compared to the energy used driving.

Flexcharging implemented several improvements to its vehicle communication algorithm during the trial which significantly improved the situation, reducing the frequency of communications depending on what the vehicle was doing. Nevertheless, it's not possible to completely eliminate this issue.

It may also be the case that the Tesla vehicles in the trial tended to wake up more of the vehicle systems than would seem necessary to undertake the communication task. As there were no other vehicle makes in the trial, we couldn't test the performance of other vehicles in this regard.

5. Vehicle-to-Grid

5.1. Introduction

The Vehicle-to-Grid (V2G) concept has a long history, well documented in an article in the Institute of Electrical and Electronic Engineers (IEEE) magazine Spectrum in March 2023[13]. The genesis of V2G was probably the academic paper "Electric vehicles as a new power source for electric utilities", written by Willett Kempton and Steven E Letendre in 1997[14].

In theory, V2G is a great idea – millions of vehicles provide energy storage that can be fed back into the grid at times of need. However, the practical application of the concept over the past two decades has been problematic and, at the time of writing, it's clear that V2G has not yet reached the point where it can be implemented at scale.

This section will discuss some of the reasons for this and provide a status report on V2G more broadly.

5.2. V2L vs V2H vs V2G

Other than traction, there are several potential uses for the energy stored in a vehicle battery. The industry has coalesced around three main definitions for these:

Vehicle-to-Load (V2L)

The vehicle is fitted with one or more household-style general purpose outlets that allow the user to plug mains-operated appliances into the car. A typical application for this is camping equipment or tradesman's tools. V2L cannot provide energy back into a residence or any other fixed installation; it is for use with portable appliances only.

Vehicle-to-House (V2H)

V2H is where energy from the battery is used to power household load. There is no grid support capability other than through the removal of household load from the grid. There are two options for this:

1) Home backup, where the vehicle is connected to the house electrical system via the main charging cable and charger, however the house is not connected to the grid at the time. This is achieved using a load transfer switch to disconnect the household load from the grid and transfer it to the vehicle supply during a power outage, the same process used to provide home backup from static home batteries. From a grid perspective, home backup may have a demand response value, although, as the load transfer process normally involves a brief period of

[13] https://spectrum.ieee.org/v2g
[14] https://www.sciencedirect.com/science/article/abs/pii/S1361920997000011?via%3Dihub

disconnection, the repeated use of this may be inconvenient (mains powered clocks lose time, internet modems reboot, etc).

2) The second option is where the charger is connected to the house while the house is connected to the grid, however export of power from the premises is prevented using logic in the charger and current transformers the measuring the current flow at the connection point. As the vehicle/charger combination is connected in parallel with the grid in this case, it must meet the regulatory and network requirements for grid-connected inverters.

Vehicle-to-Grid (V2G)

The vehicle is connected to the fixed installation, which may residential or commercial, via the charging cable and charger whilst the premises is connected to the grid. Discharging from the vehicle to the grid via the premises wiring is possible. As the vehicle/charger combination is connected to the grid and is capable of discharging energy back into the supply, it must meet the regulatory and network requirements for grid connected inverters.

5.3. Overseas Trials

Whilst there have been a number of V2G trials overseas in the past few years, most of them have been small scale involving only a handful of chargers and vehicles. These could best be described as research or technology demonstrations rather than trials.

The notable exceptions have been the three large-scale trials undertaken in the UK, partly funded by the UK Government[15]. Not all of these trials have delivered final reports yet, however details are publicly available and can be found here:

1) Octopus Powerloop, a 135 customer trial originally targeted for completion in 2022, final report not yet published – https://octopusev.com/powerloop

2) Project Sciurus, a 300 customer trial completed in 2021, final report published – https://www.cenex.co.uk/projects-case-studies/sciurus/

3) Electric Nation Vehicle-to-Grid Trial, a 100 customer trial completed in 2022, final report not yet published – https://electricnation.org.uk/

It's important to note that these have been funded trials and not commercial rollouts. To date, none of the major UK trials have resulted in on-going V2G retail energy products generally available to the public.

[15] UK V2G trials were partly funded by the UK Department for Business, Energy and Industrial Strategy and delivered by Innovate UK as part of the Flexibility Innovation Programme.

5.4. AGL's V2G Trial

The main thrust of AGL's ARENA EV orchestration project was to trial and measure the value of EV charging control to provide benefits for both the grid and customers. As covered elsewhere in this report, this was achieved in the other streams of the trial using internet-connected, remote-controllable smart chargers and vehicle API control to move charging activity into those times of the day which best matched supply availability.

Our intention with the V2G stream of the trial was similar, but with the added benefits of bi-directionality – to control the chargers to charge or discharge at those times when there were benefits to do so. The novel part of the project was the control of charging and discharging for grid support purposes using an Open Charge Point Protocol (OCPP) compatible charger management system. Free-running charging/discharging that was not centrally controlled was already being trialled overseas and there was little to gain repeating that in Australia.

It became apparent during the first 18 months of the project, however, that there were a number of impediments to achieving the aims of the trial. These were:

1) Availability of chargers

During the original scoping for the project, trial charger supplier JETcharge indicated it was planning to release the Wallbox Quasar V2G charger in Australia in early 2020. This timing suited the project, as it would allow some testing of the chargers prior to installation during 2021.

Unfortunately, availability of the Quasar in Australia was delayed by nearly two years due to standards compliance problems. This issue has been covered at length in the reports of the ARENA-funded Realising Electric Vehicle-to-Grid Services (REVS) project[16], which was similarly affected.

In summary, the initial version of the Quasar didn't comply with Australian Standard AS4777.2 2020 for grid connected battery inverters, a standard not necessarily written with all the implications of V2G inverters in mind, although it covers them. After the charger had been modified and compliance was finally achieved, the Clean Energy Council (CEC) would not approve the device; CEC approval is normally a pre-requisite of distribution network companies to connect the device to the network.

These delays pushed the availability of chargers well beyond the timeframe of the rest of the trial, which was finishing at around the time one distribution company issued special approval for connection of the Quasar charger to their network.

The Wallbox Quasar is the only V2G charger for which local standards approval has been attempted. AGL had discussions with another V2G charger[17] supplier about potential Australian availability, however the supplier elected not to approve the charger locally due to the cost and effort involved for a small sales volume.

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[16] https://arena.gov.au/projects/realising-electric-vehicle-to-grid-services/
[17] Like the Quasar, this charger had also been used in UK trials.

2) Functionality of the chargers

As this was a trial of charging orchestration, the project needed chargers that were able to be controlled remotely from the OCPP platform that had been developed to control the chargers in the smart charger stream.

Upon detailed examination of the Quasar specification, however, it became clear that the version of charger available at the time could not support this mode of operation and that further hardware and software would need to be developed to interface the chargers to the control platform. These developments were outside the scope of the project and had significant implications for cost, time, and the type of interface and amenity that we would be able to offer the customers involved.

As a result of these factors, AGL and ARENA agreed to remove the V2G stream from the trial.

The Quasar charger that was to be used in the trial is now obsolete and production has ceased[18]. A new version of this charger, Quasar 2, is currently in development and will be a CCS-compatible charger (see section 5.5). A firm availability date for this has not been announced.

Based upon AGL's experience in this part of the project, it's our view that the vehicle-to-grid concept is still two to four years away from being a commercial reality. Whilst it remains a potentially interesting development for the future, there is a large amount of work to be done in terms of standards development, the technical solution, cost reduction and vehicle availability before it becomes a realistic option for both customers and the electricity industry.

In the remainder of section 5, we cover some of the issues surrounding V2G that will need to progress before it becomes viable.

5.5. Standards

As V2G requires large-scale interoperability between many different devices made by many different manufacturers, the development of technical standards to allow this is key to the success of the concept.

There are two points in the chain where these standards are critical:

1) The interaction between the vehicle and the charger; how the two are connected and communicate with one another.

2) The interaction between the charger and remote charging management platforms.

The interaction between vehicle and charger has historically been covered by several non-compatible standards.

The Combined Charging System (CCS) standard was developed in Europe and originally published in 2011. In 2014, the European Union adopted CCS as the required standard for European vehicle

[18] https://jetcharge.com.au/solutions/vehicle-to-grid/

chargers. Today it is the predominant vehicle charging standard across most of the world except Japan and China.

The CHAdeMO standard was developed in Japan in 2010 and is predominantly used there, however it's use outside Japan is rapidly declining and most newer models of Japanese cars sold outside Japan now have a CCS charging port. The CHAdeMO standard included V2G functionality from 2014, and it remains the only formally issued vehicle charging standard with this capability. Its declining use in the global market, however, means that this V2G capability has a limited future and there are very few vehicles or chargers that support it.

As forerunner in the electric vehicle space and still the largest manufacturer of full battery EV's, Tesla originally developed its own vehicle charging standard for use with its vehicles. The Tesla charging standard is used on Tesla chargers throughout the USA. Recent Tesla vehicles, and those exported from the USA, have a CCS charging port or are compatible with CCS via an adapter, and Tesla has recently opened up its Supercharger network in many countries to CCS-compatible vehicles from other manufacturers. The Tesla charging standard does not incorporate V2G.

As CCS is the predominant charging standard globally, adoption of V2G within the CCS standard is necessary if V2G is to gain widespread acceptance. This work is underway and a version of the standard that incorporates V2G is expected to be issued around 2025. It may take a year or two beyond this for products to emerge that are designed around the new standard, and possibly longer for those products to be certified and released in Australia.

In the meantime, it's possible there may be further overseas trials of V2G using prototype technology built around draft versions of the CCS standard.

The second critical standard for V2G is the one used for communication between the charger and charging management software platforms used to manage and control large groups of chargers. For one-directional charging, the Open Charge Point Protocol (OCPP) standard, originally developed in 2009, has been widely adopted and is used for both public charging networks and residential smart charging. The Chargefox software used during the trial is an example of an OCPP platform in use today. OCPP is also supported by most chargers on the market.

The currently released version of OCPP (version 2.0.1) does not support V2G, and most charging equipment available on the market is still designed around the earlier version 1.6. It's proposed that V2G will be supported in a future update of the OCPP2.x series in the next few years.

5.6. Vehicle Availability

Availability of a wide range of V2G capable vehicles is a key element in the success of V2G. At this stage there are very few vehicles on the market that support V2G and this is not expected to change until CCS2 V2G functionality is formally adopted sometime after 2025.

One thing that is becoming more common on vehicles, however, is V2L. V2L is a simple and attractive concept for vehicle manufacturers to market, and it can be implemented easily in the vehicle without having to deal with the complex standards and compliance requirements of fixed wiring and grid connection, and without the high costs of a V2G or V2H charger installation.

The following vehicle manufacturer V2G availability summary is based on publicly available information and was correct, to the best of our knowledge, in March 2023. Where possible we have used primary sources for this information rather than relying upon media reports, which we have been found to be frequently inaccurate. The summary is not intended to be exhaustive, but it covers most of the major global electric car manufacturers, particularly those who have shown some interest in V2G.

5.6.1. Volkswagen Group

During its "power day" in April 2021, Volkswagen first mentioned V2G as being part of its technology roadmap for EVs[19]. Information from this day was very high level and strategic in nature, but subsequent media reports quoted senior VW personnel suggesting that product would be released in 2022. In December 2021, Volkswagen announced that V2G "was about to be launched" via an over-the-air firmware update to its ID. family of vehicles[20].

In September 2022, Volkswagen signed a MOU with Elia Group (the Belgian transmission system operator) to study the integration of EVs with the grid. The Elia Group press release on the subject didn't mention V2G, although the VW press release did[21].

OVO Energy subsidiary Kaluza has announced a V2G study involving Volkswagen in the UK[22]. We have been unable to find a matching announcement from Volkswagen.

No Volkswagen Group vehicle is currently being marketed as having V2G functionality.

5.6.2. Hyundai and Kia

Hyundai has V2L capability available in the Ioniq 5 and it's also available in the related Kia EV6. V2L allows customer appliances such as camping equipment and tradesmen's tools to be operated from the vehicle battery.

In April 2022, Hyundai announced that they would modify 25 Ioniq 5 EVs to test V2G in the Dutch city of Utrecht with mobility provider We Drive Solar[23]. V2G is not currently available in production Ioniqs or any other Hyundai or Kia vehicle, but Hyundai will use the project to test the concept for potential commercialisation. We have not been able to find any further publicity about this project since its announcement.

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[19] https://www.volkswagen-newsroom.com/en/press-releases/power-day-volkswagen-presents-technology-roadmap-for-batteries-and-charging-up-to-2030-6891
[20] https://www.volkswagen-newsroom.com/en/press-releases/convenient-networked-and-sustainable-new-solutions-for-charging-electric-volkswagen-models-7695
[21] https://www.volkswagen-newsroom.com/en/press-releases/elli-and-elia-group-forming-partnership-to-integrate-evs-into-the-electricity-system-15207 & https://www.eliagroup.eu/en/news/press-releases/2022/09/20220923_mou-elia-group-and-vw-elli
[22] https://www.kaluza.com/kaluza-launches-a-world-leading-vehicle-to-everything-trial-with-volkswagen-group-uk-ovo-energy-and-indra/
[23] https://www.hyundai.news/eu/articles/press-releases/hyundai-and-we-drive-solar-launch-energy-system-of-the-future-in-utrecht.html

5.6.3. Tesla

The largest manufacturer of EVs in the world, Tesla, is not currently marketing any V2G capable vehicles and has not made any formal announcements regarding the future availability of V2G.

5.6.4. Polestar (formerly Volvo)

Polestar does not currently have any V2G capable vehicles in production. It is reportedly planning to include V2G in its next generation of EVs due in 2026.

In April 2021, Polestar announced that it was founding a five-partner three-year V2X technology study in Sweden which would include the installation of two V2X charging stations[24]. We have not been able to find any further reports on this study.

5.6.5. Ford

Ford has recently released the F150 Lightning EV pickup truck in the US market. The F150 has V2L capability targeted at tradesmen on construction sites, and has been marketed as providing home backup capability (V2H) with a special charger and home integration system provided by Ford and solar supplier Sunrun[25]. This system uses a transfer switch to disconnect the property from the grid before supplying the house from the vehicle. It does not currently provide V2G capability.

North Carolina utility Duke Energy has announced a trial of V2G using the F150 to commence in 2023[26]. As similar announcement from Californian utility PG&E has been widely misreported as a trial of V2G when what was announced was a trial of home backup, a particular issue in California due to grid shutdowns during bushfires and extreme weather events[27].

5.6.6. General Motors

In the US, General Motors has announced the formation of GM Energy to provide energy management products and services[28]. General Motors and San Diego Gas and Electric (SDG&E) have announced an agreement to investigate the feasibility of integrating bidirectional EVs into the grid as a local energy resource[29].

General Motors is not currently marketing any V2G capable vehicles.

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[24] https://www.polestar.com/au/news/research-project-v2x/
[25] https://www.ford.com/trucks/f150/f150-lightning/features/intelligent-backup-power/?intcmp=reVhp-featcta-intellBackup
[26] https://news.duke-energy.com/releases/illuminating-possibility-duke-energy-and-ford-motor-company-plan-to-use-f-150-lightning-electric-trucks-to-help-power-the-grid
[27] https://investor.pgecorp.com/news-events/press-releases/press-release-details/2022/PGE-and-Ford-Collaborate-on-Bidirectional-Electric-Vehicle-Charging-Technology-in-Customers-Homes/default.aspx
[28] https://news.gm.com/newsroom.detail.html/Pages/news/us/en/2022/oct/1011-energyecosystem.html
[29] https://www.sdgenews.com/article/sdge-general-motors-explore-vehicle-grid-and-vehicle-home-technology

5.6.7. Nissan

Nissan were a forerunner in EV development with the 2010 release of the Leaf, and, with the second-generation Leaf released in 2017, remains one of the very few manufacturers currently supplying a V2G capable vehicle. The Leaf is only available with a CHAdeMO charging port.

Nissan's newly released (but not in Australia) EV, the Ariya, is a CCS2 charging vehicle that is not being marketed as having V2G capability.

5.6.8. Mitsubishi

Mitsubishi currently supplies the Outlander and Eclipse Cross plugin hybrid EVs with CHAdeMO charging ports and V2G functionality. Being hybrids, these vehicles have smaller batteries than full battery EVs – 20kWh in the case of the Outlander and 13.9kW for the Eclipse Cross. Nevertheless, if the battery is full, they have the potential to provide useful capacity for short periods in a residential situation. (The CSIRO reports a two-person Australian household uses an average of 12kWh per day[30].)

5.6.9. Toyota

Although Toyota doesn't currently have a V2G capable vehicle in production, it has announced a V2G research project with Texas utility Oncor[31].

5.6.10. Renault

In 2019, Renault built two prototype V2G Zoe's for a trial in Utrecht, Netherlands[32]. The V2G functionality did not move into the production Zoe.

In January 2023, Renault announced it was partnering with the French Atomic Energy Commission (CEA) on a long-term project to design an on-board bi-directional charger for its vehicles, slated for availability towards the end of the decade[33].

Renault is not currently marketing any V2G capable vehicles.

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[30] CSIRO Energise Insight, 4 December 2018

[31] https://pressroom.toyota.com/toyota-announces-collaboration-with-oncor-to-accelerate-ev-charging-ecosystem/

[32] https://www.renaultgroup.com/en/news-on-air/news/renault-tests-its-bi-directional-charging-system-in-utrecht/#:~:text=Recognisable%20by%20their%20specific%20design,car%27s%20battery%20to%20the%20grid.

[33] https://media.renaultgroup.com/electric-vehicles-cea-and-renault-group-develop-a-very-high-efficiency-bidirectional-on-board-charger/?lang=eng

5.6.11. BMW

BWM is currently undertaking a V2G research project with European utility EON using specially modified BMW i3 EVs being driven by two families in Munich[34]. This project is concentrating on maximising the utilisation of rooftop solar in the home through the energy storage in the vehicle.

BMW is not currently marketing any V2G capable vehicles.

5.7. Chargers

There are very few V2G capable chargers available on the global market today, and those that are, are generally built in small batch quantities for trials only. With the discontinuation of the Wallbox Quasar, there are currently no V2G capable chargers available in Australia.

Similar to the situation with vehicles, development of the next generation of V2G chargers will most likely occur when the standards issues covered in section 5.5 have been resolved and the industry is able to move forward with a standardised CCS V2G charging platform.

V2G chargers are currently very expensive. When it was on the market in Australia, the Wallbox Quasar had a price of $10,000, five to six times more expensive than a typical smart charger. There are several reasons for this:

1) V2G chargers are currently built in very small quantities and there are no economies of scale.
2) The cost of achieving standards compliance is high.
3) V2G chargers are direct current (DC) devices that are technically more complex than regular domestic alternating current (AC) chargers.

The production volume and compliance cost problems will most likely resolve themselves when sufficient level of consumer demand for these devices develops – high volume production will reduce costs significantly and compliance costs become much smaller when amortised across a large number of devices.

The DC nature of V2G means that the cost of a V2G charger will probably reduce over time to a cost comparable to that of a home solar inverter, solar inverters being a very similar technology operating at roughly the same current carrying capacity. This suggests a retail price of around $2,000 - $3,000 (in 2023 dollars) should be achievable in the long term.

[34] https://www.eon.com/de/innovation/innovation-in-aktion/innovation-news/stromspeicher-auf-vier-raedern-bmw-und-eon-kuendigen-bi-clever-an.html and https://www.eon.com/en/innovation/innovation-frontline/innovation-news/bi-clever-eon-pilot-project-shows-revolutionary-potential-of-bidirectional-charging.html

6. Customer Research

In addition to monitoring and analysing data that was collected from chargers and vehicles, our trial has had a heavy focus on customer research. We ran several rounds of surveys and one-on-one customer interviews throughout the trial, and the findings of these have been covered in our previous lessons learnt reports.

This final round of research covers the experience of trial participants at the completion of the trial and asked them to reflect on their experience across the entire trial period.

Participation in surveys and interviews was again voluntary. We continued to observe high levels of participation in our survey responses throughout the entire trial, which highlights the engagement of this trial group.

6.1. Research scope, methodology & participation

The research was completed by the research agency Perspicacious, who have conducted prior rounds of customer research on the trial. It focused on trial participants' charging and driving habits, their experience with smart charging orchestration, and future intentions for EV ownership and smart charging. The research was split into two components:

1) A quantitative online survey sent to 283 trial participants and completed by 97 trial participants, a good response rate of 34%. Participants were not incentivised to complete the survey. Data collection occurred between 7 – 19 February 2023 and the average completion duration was around 15 minutes.

2) Sixteen qualitative one on one interviews. The interview participants were selected to provide a mix of new and returning interview participants across the connected charger and vehicle API streams including promoters, passives and detractors based on their response to the NPS and CSAT ratings in the quantitative survey. The interviews comprised five NSW, four Vic, four QLD and three SA residents. Interviewees were incentivised $50 for their time.

6.2. Key profiling characteristics of survey respondents

Due to the lack of randomisation in the survey sampling, we cannot say the demographic makeup of survey participants is representative of the broader EV market. However, anecdotal evidence and other EV research suggests common traits emerging within the current cohort of EV owners. Below are a few highlights of the common traits of our survey respondents:

- 89% of respondents live as a couple; 56% with child/ren in the household and 33% without.
- 91% live in free-standing house.
- 52% have a home solar PV system, while a further 27% have a solar system with battery storage.
- 63% of respondents are aged 35-54.
- 49% of the survey sample are employed in a professional and 24% in a managerial role.

- 22% of respondents have an annual household income of >$250k, and 23% did not want to reveal their earnings.
- 71% of respondents are employed full-time.

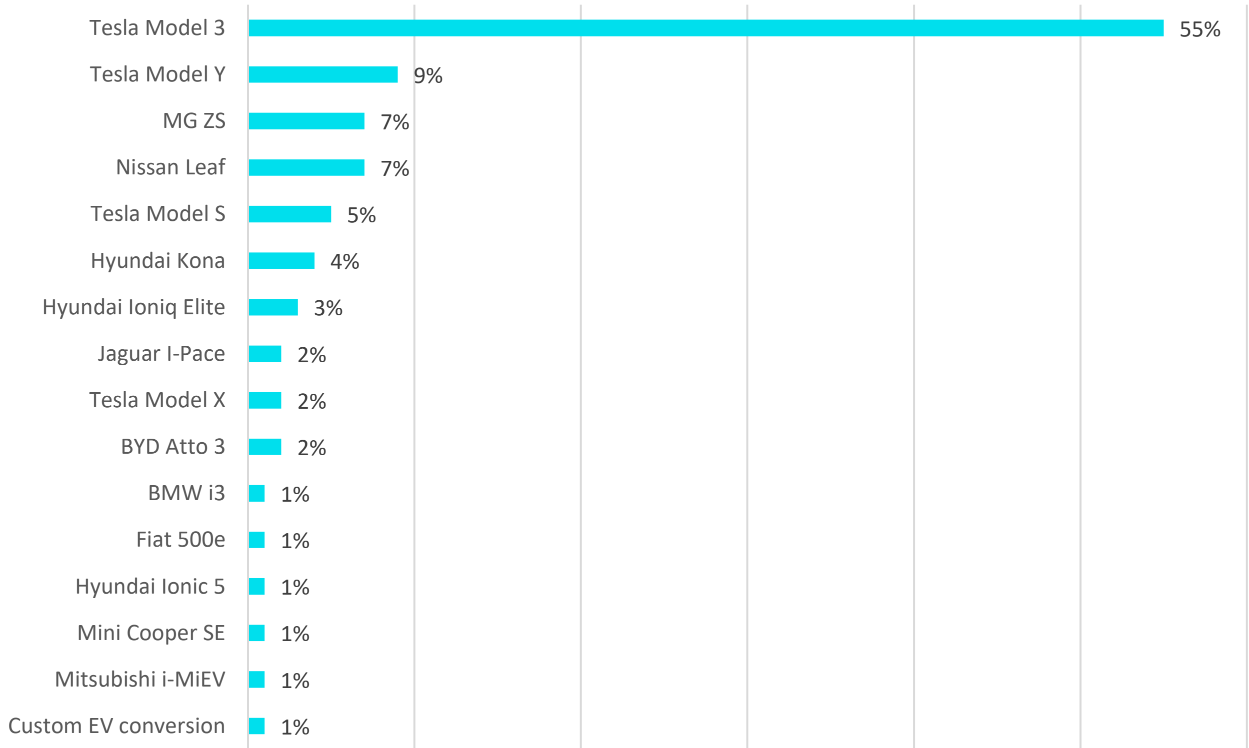
6.3. Vehicle ownership of trial participants

Unsurprisingly, the Tesla Model 3 was the most common make and model owned by survey respondents (55%), followed by Tesla Model Y (9%), MG ZS (7%) and Nissan Leaf (7%).

While 70% of respondents had at least one ICE vehicle in the household, they considered the EV to be their primary vehicle.

The positives people associate with having an EV included: cost saving (90%), convenience of home charging (82%) driving experience/performance (82%) and low maintenance (77%). Insufficient charging infrastructure was the most common negative (64%).

Charging predominantly occurs at home (73%), and when it comes time to buy a new car in the future, 98% expect to buy an EV.



Q: For classification purposes, please select the brand and model of your electric vehicle/s. Note: Eleven respondents noted they own multiple EVs, which is why the total is >100%.

Makes and models of trial participant EVs

6.4. Key lessons from the research

6.4.1. Strongly positive trial experience

This final round of research revealed that after a positive installation and onboarding experience, the first few months of managed charging was considered a shaky start, which then improved across the second half of the 2022 and ended on a high note after improvements to our communication and community interaction processes. This was evidenced by the strong CX measurement results at the conclusion of the trial, with final NPS and CSAT ratings of +40.0 and 8.7/10 respectively.

The greatest factor contributing to a positive overall trial experience was a perceived improvement charging control events, due to improved communications which provided greater awareness of the events and how to engage with them via the smart charging mobile apps.

This was especially insightful given that, since our previous round of research, we increased the frequency and duration of the managed charge sessions and expected that this may have a negative effect on the trial participants' perception of them. This finding highlights the importance and power of customer communication, education and expectation-setting for smart charging.

Net Promoter Score (NPS) breakdown

+40	58%	25%	18%
NPS	Promoters	Passives	Detractors

> *"I was at a dinner party recently one of our friends started criticising AGL – mostly because the share price had recently tanked – but I actually spoke out and defended them, explaining how they were investing in this trial which demonstrates that they were thinking about the future and trying to do something good."*

6.4.2. Overall ratings of the trial experience

Ratings were sought from respondents on key elements of the smart charging trial with 5 indicating that expectations have been met, 6 – 10 indicating that the experience was above expectations and 1 – 4 indicating it was below expectations.

Encouragingly, “overall trial experience” received an extremely strong rating, with 93% of participants stating that the trial met or exceeded their expectations, and 59% indicating it was well above their expectations.

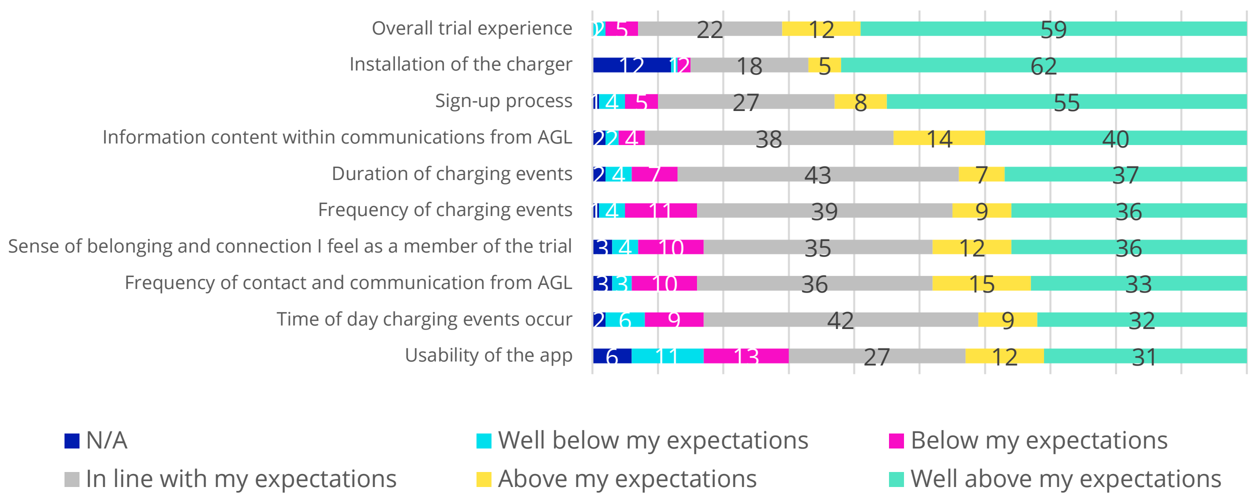
Installation of the charger stands out as the highest-ranking item with an average rating of 8.1, with 62% of participants rating their experience as well above their expectations (8 or above). This item was consistently called out as a strongly positive aspect of the trial.

Communications saw a positive uplift over time, with the information content in communications receiving an average rating of 6.8 in this survey (up from 4.6) and the frequency of contact and communication receiving an average rating of up to 6.4 (up from 4.3).

The three items measuring aspects of the charging events performed similarly and largely aligned or exceed participant expectations, with the duration receiving a mean rating of 6.5, frequency receiving a mean rating of 6.4, and time of day receiving a mean rating of 6.1.

The sense of belonging and connection trial participants have felt as a member of the trial also increased, with 36% stating that it has been well above their expectations (net 8-10 rating) which contributed to the positive mean rating of 6.4.

36% of respondents did not have to engage AGL on issues resolution, but among those that did, the experience was largely positive at 6.1.



Q: Based on the experience you EXPECTED to have with the trial, please consider the following aspects in terms of whether or not your expectations have been met.

Ratings of key aspects of the trial experience

Positives & negatives associated with the trial

The final round of research revealed that the trial experience improved across the year as we improved customer communications and community engagement.

The positives and negative themes that emerged in this round of research were largely consistent with the 2022 findings; however, there was a shift after the mid-point in the trial, with people no longer reporting feeling underutilised, disengaged or concerned about insufficient participation. Indeed, they felt that engagement with AGL had significantly improved and appreciated the opportunity to connect with other trial participants and AGL staff via the online forum, and the improvement in email communications from AGL. Nonetheless, some individuals noted that they thought the AGL trial staff could have called upon their expertise in EVs and power generation.

Positive themes	Negative themes
Receiving the charger and having improved charging capacity and speed	Vehicle not charging as expected / faulty charger
Seamless and unobtrusive charging events	Not leveraging free solar production
Contributing data for better decision making and problem solving	Lack of clarity on data capture and usage
Receiving bill credits	App issues / unclear how to use app
Positive support experience when required	Bill credits not applied
Feeling engaged in trial, in particular connection with AGL and other trial participants through the online forum and email communications from AGL	The vehicle is woken up too often

6.4.3. Likelihood of signing up to a smart charging service in the future

One of the most promising findings from the trial was that 84% of survey respondents consider it likely that they would sign up, on an ongoing basis, to a smart charging service.

As might be expected, financial enticements were key to signing-up on an ongoing basis, while the qualitative research revealed the importance of an app to deliver against customer experience expectations.

It was also noted that whilst these participants were engaged in their household usage and, as such, were able achieve similar outcomes by setting schedules in the vehicle and "micro-managing" their plug-in times to align with solar generation, they noted that other family members weren't so engaged so a smart charging service would be ideal for them in particular. We believe that this would align more closely with user needs once EVs become more prevalent in the mass market.

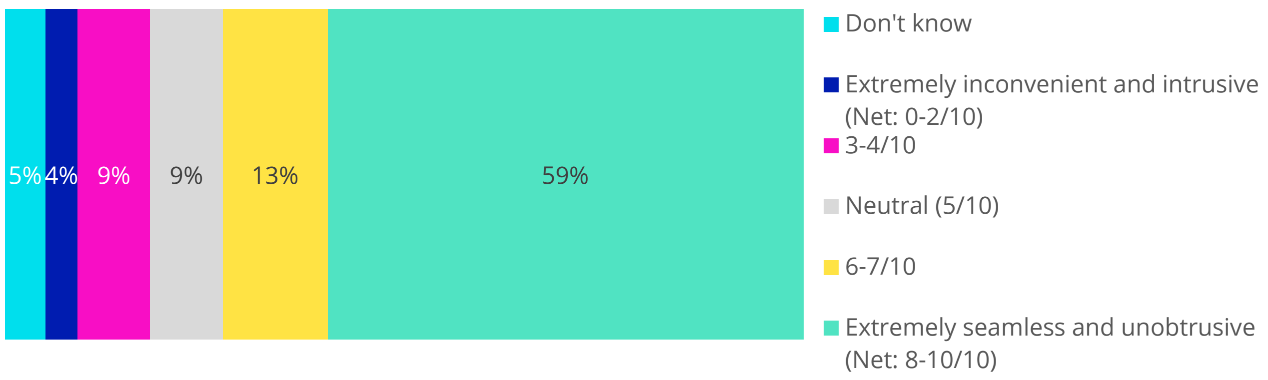
In addition to the financial incentives, our qualitative research revealed that an increased sense of collective responsibility was also driving the high likelihood of signing up to a smart charging service in the future. This was driven by participants over-indexing on power awareness and passion for the associated technology. Whilst we understand that this may not be the norm for the masses just yet, it is a promising sign that in the future, as distributed energy technology and EVs become more widespread, this increased sense of collective responsibility will come along with it.

> *"I really like the idea, I think we need to have some sort of controlled charging because EVs use a lot of energy so we have to have some way of administering that and I think, you know, the controlled charging app is probably ideal."*
>
> *"If there was an opportunity in the future to do it, I'd be jumping on board as well."*
>
> *"I trust myself to use the pricing signals and micro-manage it myself to the point that I get the best outcome – but if they had a system where that was the outcome anyway and that was easier for me, then definitely I would join that program."*
>
> *"Yeah, as a concept I do think it is worthwhile… if someone asked me if I wanted to have controlled charging, I would want to do it myself. But that is me, my daughter would plug in whenever, would never check, she doesn't pay the bills. My wife is getting better at it, but it has taken my wife 1.5-2 years to learn to check if we are generating excess power from solar to minimise grid draw."*
>
> *"I think they need to do some controlled charging, but is there a way to have more flexibility. E.g. if they knew we had a power wall and were exporting power to AGL, couldn't they just integrate this and make sure that we are only charging when we are exporting to the grid? Give you the option to decide where to direct your power. If it was fully integrated I would do it, but I don't trust them to get it right, they get readings and billing wrong, so I would need details and be able to verify that what they said they were doing is what they were actually doing."*

6.4.4. Impact of charging control events

Day-to-day, trial participants generally found the impact of controlled charging events to be seamless and unobtrusive with 72% providing a positive net rating of 6 or above, with a mean rating of 7.5.

Only 13% of participants described the events as in any way inconvenient and intrusive (rating 4 or below). Reflecting an increased awareness and understanding of the controlled charging events, 5% answered 'don't know' to impact of the controlled charging events in February 2023, down from 22% in June 2022.



Q: On a scale of zero to ten where zero means 'extremely inconvenient and intrusive' and ten means 'extremely seamless and unobtrusive' how would you rate the charging events in terms of their impact on your life day-to-day?

Impact of charging control events on participants day-to-day life

"I thought there would be more control by them, like not only limiting controlling but forcing it at certain times."

"I was slightly concerned at the beginning because with my shift work on how it would charge the car when I charge irregular times depending on my shift pattern. But there was maybe 5 times overall that I could count that I had to have a slight concern about when it was going to be charged or not ready for the day. It was easier than anticipated."

"The only time I probably was affected a little was when they changed one of the schedules to include the morning limitation... It was only a problem because at 8am I am getting full solar, I could override it, but I tried not to override the schedule as much as I could. I would never charge from 4-9pm anyway because of the grid."

6.4.5. Reasons for opting out of smart charging events

As described in section 3.3.7, the opt-out level from charging control events was very low. This was backed-up by our research, with 42% of participants stating that they had not opted out of any of charging control events at all.

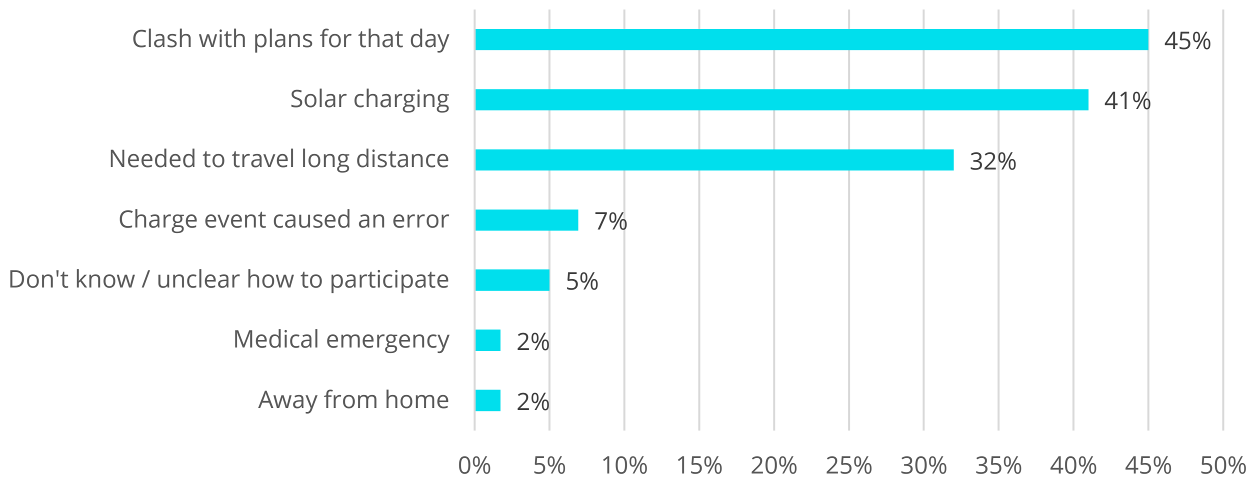
This figure was down, however, from the 73% recorded in June 2022, and likely reflects:

a) the increase in duration and frequency of events

b) an increased understanding among participants of when charging control events were occurring and how to opt out via their smart charging apps.

For the participants who had opted out of at least one smart charging event, the most common reason given was that the timing of a managed charging session clashed with their driving needs on that particular day, with 45% of respondents citing this. Almost equally common was wanting to charge during solar generation hours, with 41% of respondents citing this as a reason for opting out of a session.

In the June 2022 research, the most common explanation for why participants opted out of charging control events revealed confusion and/or a lack of communication, with 54% of trial participants commenting to this effect. In this most recent round of research, however, there was a notable improvement, with only 9% stating they needed to opt out due to being unclear about how to participate. We expect this was because of the increased the frequency and content of communications in the second half of the trial.



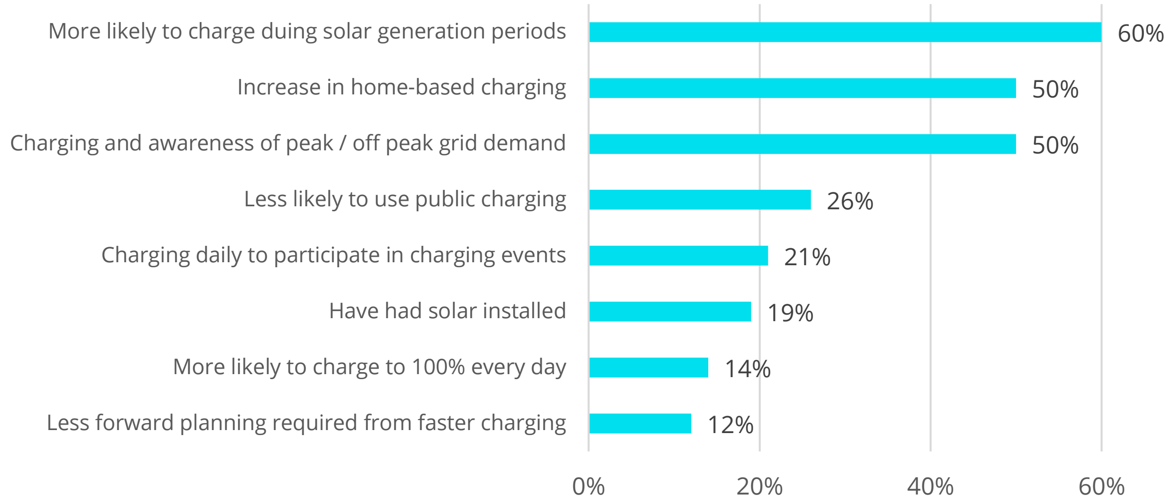
Q: And which of the following best explain some of the reasons as to why you've needed to opt out of charging events? Note: The question permitted respondents to cite multiple reasons, which is why the total is >100%.

Reasons for opting out of smart charging events

6.4.6. Charging events and their influence on future charging behaviour

Most people found controlled charging unobtrusive and appropriately scheduled, and as such, opting out occurred infrequently. This had an unexpected flow-on effect, as our research revealed that participating in managed charging events positively impacted charging behaviour and awareness of society's power needs, and also increased expectations of future charging services. In fact, 43% of trial participants reported that after the managed charging events ceased in January 2023, they changed their charging habits as a result of participating in the trial.

Among those for whom charging habits changed, the most common descriptions of how they changed were that they were more likely to charge at peak solar generation periods (60%), more likely to charge at home (50%), and more aware of peak and off-peak grid demand therefore likely to charge at off-peak times (50%).



Q: Which of the following best describes how your charging habits have changed? Note: The question permitted respondents to cite multiple reasons, which is why the total is >100%.

Reasons for changed charging behaviour due to trial participation

> *"After joining the trial I became more thoughtful about when I was charging and the times I was charging."*
>
> *"Now that the trial has ended we are doing it from our car and aligning with peak and off-peak rates to charge at the same times as the trial because, yeah, I think that was a good schedule."*
>
> *"I look at Tesla app and see if car is fully charged and battery level before sun goes down. Also, the Tesla app shows me the car and our power wall - today we are only generating 7kw solar, but air conditioner using 7.2kw - so I won't be charging the car today."*

6.4.7. A shift from individual/household to societal focus

In the June 2022 qualitative research, a key finding was participants' interest in the notion of being 'self-sufficient' versus 'grid-dependent'. This included an interest in emerging technologies that would enable bi-directional charging.

In the February 2023 research, there was a notable shift in focus to a contribution to the grid and the broader society's power needs, rather than solely fulfilling individual/household power needs. Nonetheless, potentially being able to be self-sufficient if needed remained an item of pride for those with solar systems.

This increased interest in meeting society's collective power needs was motivated by participants over-indexing on power awareness and a passion for the underpinning technology, although environmental considerations were also at play.

Furthermore, many explained that the trial itself had driven this sense of collective responsibility, explaining that participating in the trial made them think more about the impact of their EV charging on the grid.

This shift in focus to societal impact had a positive influence on participants' likelihood to sign up to a charging orchestration service on an ongoing basis.

> *"I really like the concept [of controlled charging], I really like that fact that as EV owners we can have some input into stabilising the grid and potentially in the future, if there was a vehicle to grid, vehicle to load or vehicle to x capability, I think it would be a great way to help electricity companies not have to put so much infrastructure in."*
>
> *"[AGL] will have more business [by investing in sustainable energy sources and charging controls] because prices will come down, they will have energy solutions they can provide, not just all coal, better options and better for environment. By all means, I am not one of those big greenie advocates, but we all need to do what we can to keep the future happening for our children. So, yeah, keep working towards sustainability."*

6.5. Closing thoughts on the research

The final round of research has been incredibly insightful, and we're again thankful for the feedback and engagement that our participants have provided throughout the trial. Their input has allowed us to refine our approach and ensure their experience in the trial was, for most participants, an extremely positive one.

The data and feedback received clearly suggests that smart charging is a desirable proposition for EV owners, provided it's done right: giving control to the EV owner when necessary, providing clear communication and expectation setting, and importantly sharing the value back with the customer.

The insights we've gained through the research will no doubt help us create better smart charging products for future generations of EV owners, which will not only help connect the EV into the 'whole of home' energy ecosystem and reduce the cost of charging their vehicle, but also help minimise the impact of home EV charging on the energy network.

On a personal level, those of us working on the trial have been quite pleased with the positive response we've received and are encouraged by the attitudes of the participants towards EV ownership. In particular, the shift that we observed across the trial from an individual/household level to societal focus was unexpected and hopefully a sign of things to come as EVs become more widespread and Australians shifts to a greener, electrified future.

7. DNSP Engagement

The Distribution Network Service Providers (DNSPs) that elected to participate in the trial were:

- United Energy (later expanded to include Citipower and Powercor, which are under the same corporate umbrella)
- AusNet Services
- Jemena
- SA Power Networks
- Ausgrid
- Endeavour Energy
- Energy Queensland (Energex and Ergon)

The DNSPs participated through their presence on a Technical Reference Group, which met every six to nine months to discuss aspects of the trial design, operation and research findings. A further Technical Reference Group meeting is currently being organised for AGL to present this final report to the group.

Further to this, AGL entered an arrangement with the United Energy/Citipower/Powercor DNSP to test the response of the controlled chargers for network purposes on specific days nominated by the DNSP during the 2022 summer. Further details of this testing are provided in section 3.3.2.

8. Knowledge Sharing Activities

Key knowledge sharing activities undertaken during the project included:

- Presentation to WA Government Department of Energy, 8 September 2021
- Presentation to ARENA DEIP EV Grid Integration Reference Group, 16 September 2021
- Presentation on the trial and the integration of EVs into the Australian energy market to the Australian Energy Market Commission (AEMC) on 13 December 2021
- Participation in ESB EV policy workshop - Residential charging: equipment standards, interoperability and communications standards, 22 March 2022
- Participation in ESB EV policy workshop - Public charging: connections, tariffs, roaming, technical standards, 24 March 2022
- Participation in ARENA DEIP EV Grid Integration Reference Group Meeting, 4 May 2022
- Participation in ARENA DEIP EV Grid Integration Reference Group Meeting, 6 July 2022
- Participation in REVS Knowledge Sharing Working Group meeting, 1 August 2022
- Presentation to ESB Electric Vehicle Smart Charging Issues Paper Stakeholder Webinar, 2 August 2022
- Participation in ARENA Managed Charging Catch-up Meeting, 24 August 2022
- Participation in ARENA EV Knowledge Sharing Workstream meeting, 31 August 2022
- Presentation to ARENA DEIP Dive - EV and Market Integration Knowledge Sharing Forum 12 September 2022
- Numerous one-on-one meetings to discuss the trial with DNSPs across Australia and New Zealand
- (Planned) participation in the ARENA EV Insights Forum, 26 July 2023