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Insights from the Realising Electric Vehicle-to-Grid Services Project – Final Report

Prepared by ENERGEIA for ARENA

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Disclaimer

This report, which the Australian Renewable Energy Agency (ARENA) commissioned, presents Energeia's findings and insights from the *ARENA Realising Electric Vehicle-to-Grid Trial.* The report is provided as is, without any guarantee, representation, condition or warranty of any kind, either express, implied or statutory. ARENA and Energeia do not assume any liability with respect to any reliance placed on this report by third parties. A third party that relies on the report in any way assumes the entire risk as to the accuracy, currency or completeness of the information contained in the report.

To the best of ARENA and *Energeia*'s knowledge, no conflict of interest arose during the course of preparing this report. While Energeia has previously conducted reports, evaluations and other work for ARENA, Energeia has not received any grant funding from ARENA.

Executive Summary

Background

The Realising Electric Vehicle-to-Grid Services (REVS) project constituted the first time a fleet of vehicles had been used to supply Frequency Control Ancillary Services (FCAS) to the National Electricity Market (NEM).

The aims of the REVS trial included:

- Understanding the specific technical impediments of vehicle-to-grid (V2G) energy transfer and introducing new technologies, such as operating envelopes, to help accommodate high local demands when overall network capacity allows;
- Observing if chargers are capable of FCAS services when configured to the AS4777.2:2020 standard, and if the current standards are compatible with V2G, or if they require updating;
- Demonstrating how a business case could be operated in the context of fleet operators accelerating the electrification of their fleet; and
- Quantifying the potential economic value and examining the V2G user experience and preconception to justify V2G implementation.

While the trial encompassed 51 chargers in total, data was available for only 38 chargers, and discharge data was only available for 29 of them. Nevertheless, the sample size was sufficient for meaningful analysis.

Scope and Approach

The Australian Renewable Energy Agency (ARENA) engaged Energeia to analyse the data collected from the REVS trial to identify key findings of greatest interest to stakeholders. Based on the available data, this report focused on the charging habits of commercial EV drivers, the probable bidding capacity, and the potential business case for fleet operators to bid into FCAS markets using V2G.

To achieve ARENA's key objective of gaining maximum insight from the REVS trial data for key stakeholders, Energeia developed the following approach encompassing four components:

1. **Data Collection –** After receiving data from ActewAGL, Energeia uploaded that material to its secure database, and examined it collaboratively with project partners ActewAGL and JET Charge;
2. **Data Quality Assessment –** Energeia analysed the datasets and reviewed the trial specifics to determine the overall data quality and improve the accuracy of the insights;
3. **Develop Key Insights –** Using the available data, Energeia analysed commercial EV driver charging habits, potential fleet bidding capacity, and the potential benefits of using V2G to bid into FCAS markets;
4. **Validation and Documentation –** Energeia validated the key insights with REVS trial participants prior to writing the insights report, as well as delivering an accompanying presentation to a wider audience of industry stakeholders for feedback.

Key Findings

The key findings from this analysis were:

- The average electric vehicle could have earned ~$12,000 participating in the NSW FCAS raise regulation market or ~$2,600 in the NSW FCAS raise 60-second contingency market, based on 2022 data;
- The average electric vehicle could earn ~$9,000 from participating in the NSW FCAS lower regulation market, or ~$2,000 from participating in the NSW FCAS lower 60-second contingency market, based on 2022 data;
- Vehicles were often fully charged when FCAS were required, so charging behaviours need to be managed to ensure enough headroom to participate in the FCAS lower markets; and

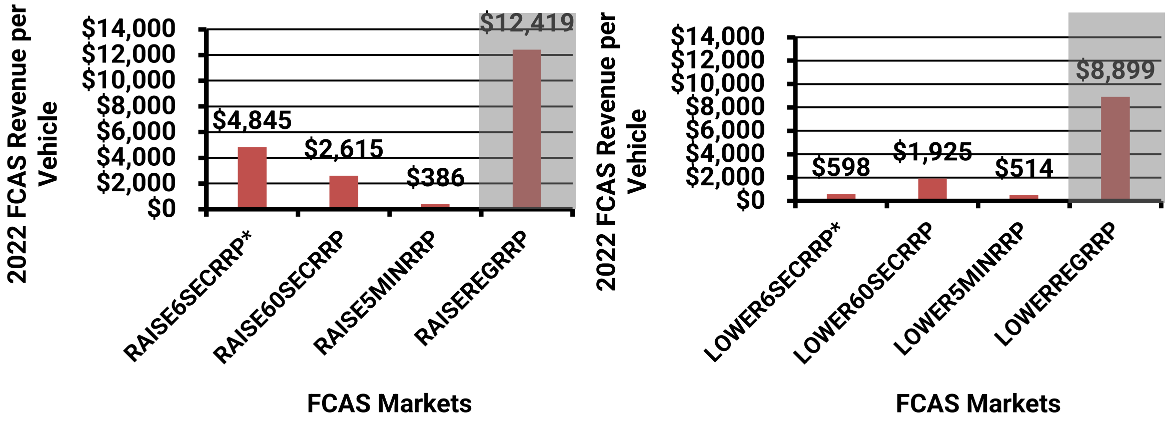
- Participation in the contingency FCAS market is unlikely to have significant impact on driver experience and EV battery degradation.

These findings are further explored below.

V2G Benefits

An analysis of potential revenue earned from participation in FCAS markets by trial vehicles revealed that FCAS could significantly improve the business case for EV adoption for business fleets. Figure E3 illustrates the estimated potential revenue per vehicle participating in the FCAS raise and lower markets.

Figure E1 – Potential Raise (Left) and Lower (Right) Revenue per Vehicle (2022)



Source: REVS Trial Data (2022), NEMOSIS (2022), Energeia (2023)
*V2G was not legally allowed to bid into this market in the REVS trial

Energeia found that the average vehicle could earn ~$12,000 participating in the NSW FCAS raise regulation market or ~$2,600 in the NSW FCAS raise 60-second contingency market in 2022. Similarly, the average vehicle could earn ~$9,000 from participating in the NSW FCAS lower regulation market, or ~$2,000 from participating in the NSW FCAS lower 60-second contingency market. The data revealed that FCAS prices typically peaked in the late afternoon to early evening for the period observed, which aligned well with commercial vehicle availability. Furthermore, the revenue that can be earned is further limited by the capacity of the charger. For example, if the charger capacity were raised to 15kW, the 60-second raise revenue per vehicle would increase to $5,604.

Due to the nature of the FCAS regulation market, which reacts to lots of small changes in grid frequency, participating in this market could result in batteries sustaining increased charge/discharge cycles. This may shorten the lifespan of EV batteries, making the thereby proportionately reducing the revenue-generation potential of the FCAS regulation market but still rendering it viable. The REVS project did not include this market.

Should V2G grow in popularity, FCAS prices and revenues might fall due to an increased supply of energy resources capable of frequency control. That scenario could make the business case less appealing because EV owners may not want to risk increased battery wear and tear amid a market with diminishing monetary returns.

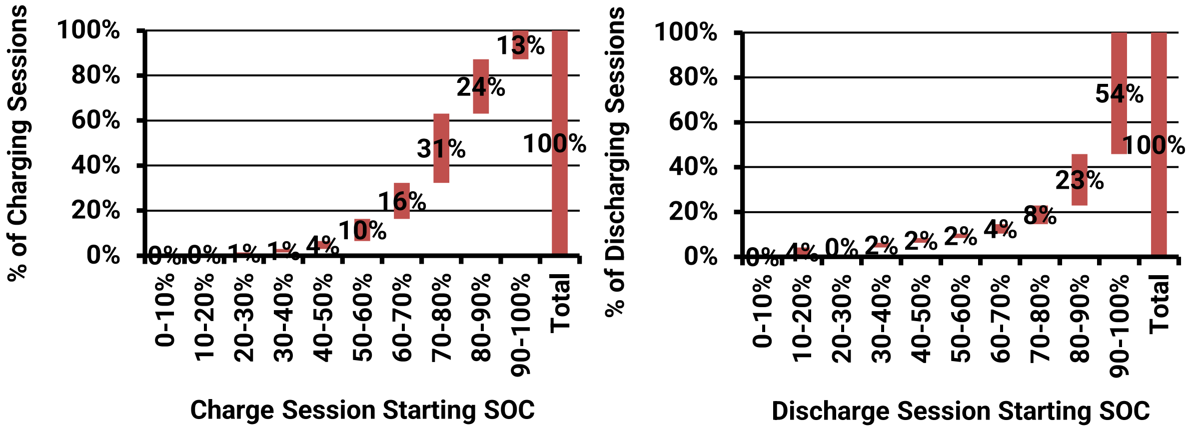
Charging Sessions

Analysis of charger data revealed that most charging sessions started between 10am and 5pm, reflecting typical business hours. About 99% of charging sessions and 100% of discharging sessions occurred on weekdays, with little variation in charging profile by building or building type. This pattern was expected given that the buildings under study contained government organisations that typically operate from 9am to 5pm. The results of this trial therefore may not be applicable to businesses that operate outside of these hours, such as recreation facilities, supermarkets, and manufacturing plants.

The state of charge (SOC) of the vehicles during charging and discharging, shown in Figure E1, was a key data point in this trial. It gave an indication of the amount of spare capacity that could be used to participate in the FCAS markets when EVs are first plugged in. More than half of the sessions started when the vehicle had an SOC of between 70% and 90%, which indicated that the cars in the trial were not driven far between sessions.

More than half of the discharging sessions started when the vehicle had an SOC of more than 90%, meaning that when FCAS were required, the vehicles were often fully charged.

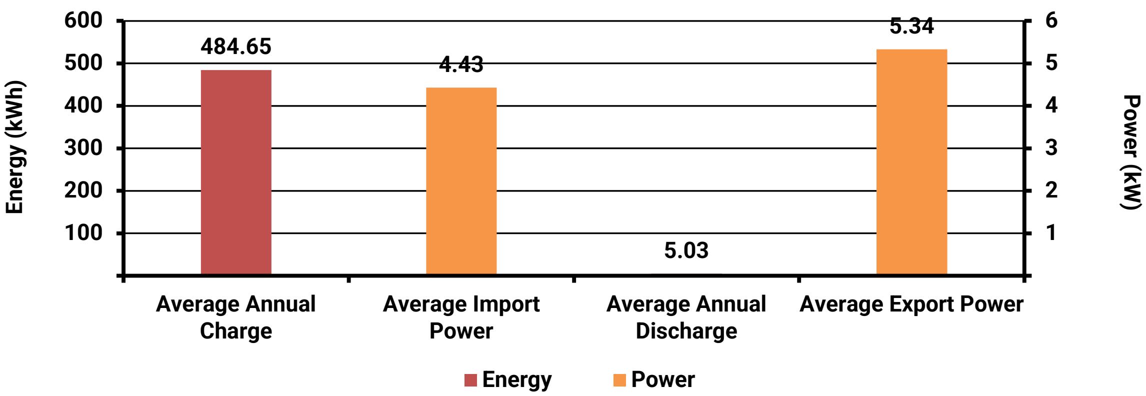
Figure E2 – Charging (Left) and Discharging (Right) Session Starting SOC



Source: REVS Trial Data (2022)

The total energy exported from EVs was around 1% of total charging energy, highlighting how the trial vehicles were rarely called upon to provide FCAS services. Thus, a minimal amount of energy was discharged from their batteries, totalling to 0.146MWh compared to 18.4MWh of energy imported during 2022. This finding indicated that participation in the contingency FCAS market is unlikely to have significant impact on driver experience or EV battery degradation, as Figure E2 demonstrates.

Figure E3 – Average Charge and Discharge Energy Flow and Power from Trial Chargers



Source: REVS Trial Data (2022)

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Structure of this Report

This report is structured as follows:

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- **Data Quality** – Data Quality covers the key features and limitations of the data collected and analysed
- **Charging Session Insights** – Charging Session Insights contains Energeia's insights from analysis of REVS trial data, including session start times, SOC, power and energy consumption, and load profiles
- **V2G Benefits** – V2G Benefits contains the potential economic value to EV owners of idle EVs that are plugged in and available to participate in the FCAS raise and FCAS lower markets.

1. Background

This section provides insight into the motivations and structure of the REVS project and briefly describes the purpose and function of the FCAS market.

1.1 The REVS Project

The REVS project was intended to determine the potential role of EVs in the FCAS market for EV owners, market participants, and grid operators. The project constituted the first time a fleet of vehicles had been used to supply FCAS to the National Electricity Market (NEM). Other aims of the REVS trial included:

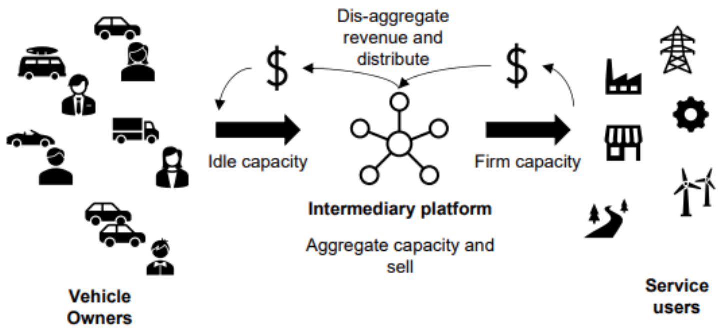
- Understanding the specific technical challenges with V2G and introducing new technologies such as operating envelopes to help accommodate high local demands when overall network capacity allows;
- Observing if chargers can provide FCAS services when they are configured to the AS4777.2:2020 standard, and if the current standards are compatible with V2G, or if they require updating;
- Demonstrating how a business case could be operated, in the context of fleet operators accelerating the electrification of their fleet; and
- Quantifying the potential economic value and examining the V2G user experience and preconceptions, to justify V2G implementation and make the transition as seamless as possible through user feedback.

The REVS project included eight participating agencies, in the following roles:

- **Australian Renewable Energy Agency (ARENA)** – provided funding for the project as a part of the Advancing Renewables Program;
- **Australian National University (ANU) –** collected and disseminated knowledge gained from the project with the wider industry, with responsibility for mapping the future path to wider V2G uptake;
- **ACT Government** – acted as the fleet owner and energy customer, and also received a share of the revenue from the vehicles;
- **SG Fleet Australia** – operated the vehicle fleets and managed vehicles and bookings;
- **JET Charge** – ensured that the EV chargers complied with local standards and responded to frequency control events, and built the control cloud and control box that enabled FCAS response;
- **Nissan Motor Co. (Australia)** – provided vehicles, warranty support, and worldwide V2G expertise;
- **Icon Distribution Investments Ltd (ActewAGL Distribution)** – functioned as the intermediary data holder between JET Charge and Energeia; and
- **Evoenergy** – established the technical connection between the chargers and the energy market as the electricity distribution network operator.

The REVS trial intended to aggregate the available spare battery capacity from participating EVs to bid into the FCAS market at specific times of the day, thus generating revenue for these vehicle owners. Figure 1 illustrates that process.

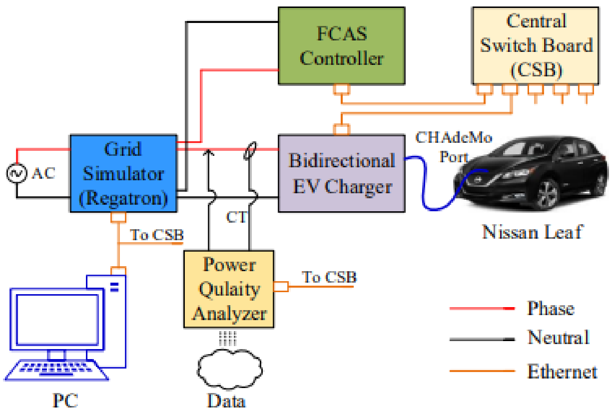
Figure 1 – REVS Revenue Procurement Example



Source: Australian National University – Creating value from V2G (2022)

The trial consisted of 51 Nissan Leaf vehicles and 51 bidirectional Wallbox Quasar chargers across 11 buildings. Each EV charger was connected to the grid simulator via a CHAdeMO port, with FCAS requests coming from an FCAS controller that modulated the charge/discharge sessions of the EV through Ethernet communication. The power meter measurements were compared to the charger data acquired from the point-on-wave meter. Figure 2 summarises each of these components and how they were integrated together within the trial.

Figure 2 – REVS Trial Setup



Source: Australian National University – Evaluation of FCAS Capabilities of a V2G Capable EV Charger: A Case Study (2022)

The data obtained from Evoenergy included charger data, booking data, and the time stamps of grid events. These were used to determine the economic value of using EVs in the FCAS market, by calculating the revenue that could be earned by bidding into the different FCAS markets described below.

1.2 Frequency Controlled Ancillary Services

FCAS are an essential electricity system service designed to maintain frequency stability by balancing supply with demand in the power grid. Supply that exceeds demand causes the grid frequency to rise. In this case, and the context of this trial, connected EVs receive a signal to consume energy from the grid (FCAS lower) through V2G. When demand exceeds supply, grid frequency will decrease, which is then rectified by signalling EVs to dispatch energy into the grid (FCAS raise) through V2G.

The Australian Energy Market Operator (AEMO) sets a target for FCAS capacity in each market, and registered generators and loads can bid into them. AEMO selects the lowest-priced bids first to meet the capacity target, and then uses the marginal price to set the price for the market.

EV owners could generate revenue using their V2G-enabled cars and chargers to bid into the FCAS markets and furnish FCAS raise or lower services by discharging into or charging from the grid at appropriate times. Their participation additionally would lead to reduced demand on fossil fuel generators if they were the alternative.

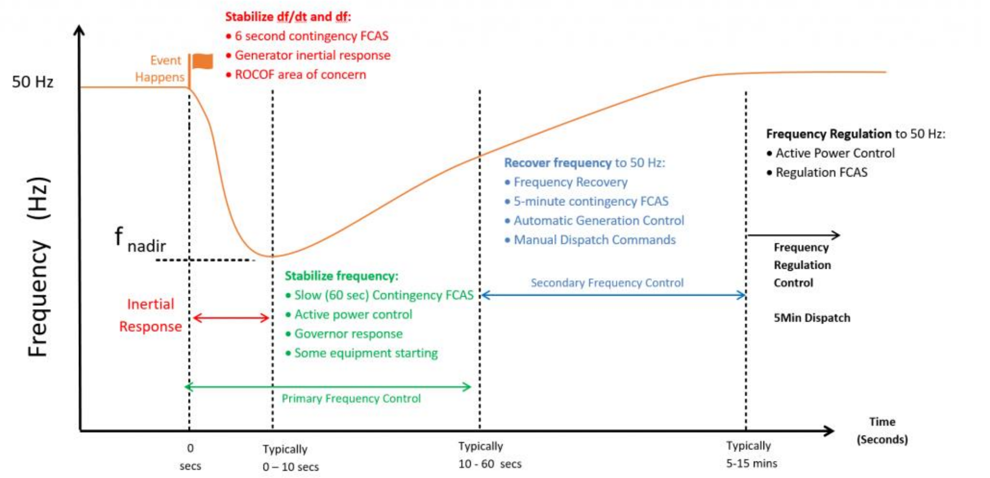
The NEM has 10 FCAS markets, which are divided into two categories:

- regulation FCAS; and
- contingency FCAS.

Figure 3 shows what would occur in the FCAS markets during a frequency excursion event and how each market would respond. Regulation frequency control by AEMO corrects minor discrepancies in the supply and demand balance. Anytime the grid frequency deviates outside the normal operating range of 49.85–50.15 Hz, the automatic generation control (AGC) system sends control signals to FCAS providers to alter their output to return within the safe operating band. In regulation FCAS, frequency deviation is continually monitored and rectified.

Contingency frequency control corrects the demand and supply balance, following a major contingency event, such as the loss of a generating unit, major industrial load, or transmission event.[1] Dispatching in contingency FCAS markets is far less frequent than in regulation FCAS markets,[2] making this market ideal for EVs as a result of exerting minimal detrimental effects on driving habits and battery cycling.

Figure 3 – Illustrative Example of a Frequency Excursion Event



Source: WattClarity by Global-Roam (23 March 2017) Let's talk about FCAS. Available from: https://wattclarity.com.au/articles/2017/03/lets-talk-about-fcas/
The 1-second service is very new (initiated 9 October 2023), so it is not included in the diagram. ROCOF = Rate of Change of Frequency.

Contingency FCAS consists of eight markets:

- 1-second;
- 6-second;
- 60-second; and
- 5-minute markets,

each of which has a raise and lower scenario. Regulation FCAS has raise and lower markets.

In the REVS trial, EV owners participated in the 60-second and 5-minute raise and lower markets.

[1] AEMO (2023) Guide to ancillary services in the National Electricity Market. Available from: https://aemo.com.au/-/media/files/electricity/nem/security_and_reliability/ancillary_services/guide-to-ancillary-services-in-the-national-electricity-market.pdf

[2] AEMO (2022) Market ancillary service specification. Available from: https://aemo.com.au/-/media/files/stakeholder_consultation/consultations/nem-consultations/2022/amendment-of-the-mass/final-determination/market-ancillary-services-specification---v80-effective-9-oct-2023.pdf?la=en

2. Scope and Approach

Knowledge sharing is a key component for improving the competitiveness of renewable energy technologies and increasing the energy supply of renewable energy in Australia. The ARENA Act specifies knowledge sharing as a function of ARENA and requires ARENA to:

- Store and share information and knowledge about renewable energy technologies;
- Collect, analyse, interpret, and disseminate information and knowledge relating to renewable energy; and technologies and projects
- Promote the sharing of information and knowledge about renewable energy technologies.

To fulfill these obligations, ARENA established a knowledge sharing team that ensures dissemination of knowledge among stakeholders through various means, including webinars, workshops, forums, reports, or online banks.

Energeia worked alongside ARENA as part of the knowledge sharing program and was responsible for analysing data acquired from the REVS project from which it identified digestible insights for a wider audience including key stakeholders.

2.1 Scope

ARENA engaged Energeia to analyse the data collected from the REVS trial to identify key findings of greatest interest to stakeholders. Based on the available data, this report focuses on the charging habits of commercial EV drivers, the probable bidding capacity, and the potential business case for fleet operators to bid into FCAS markets using V2G.

2.2 Approach

To achieve ARENA's key objective of gaining insight from the REVS trial data, Energeia developed a project approach encompassing four components:

1. **Data Collection** –After receiving data from ActewAGL, Energeia uploaded that material to its secure database and examined it collaboratively with ActewAGL and JET Charge;
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4. **Validation and Documentation** – Energeia validated the key insights with REVS trial participants prior to writing the insights report, as well as delivering an accompanying presentation to a wider audience of industry stakeholders for feedback.

3. Data Quality

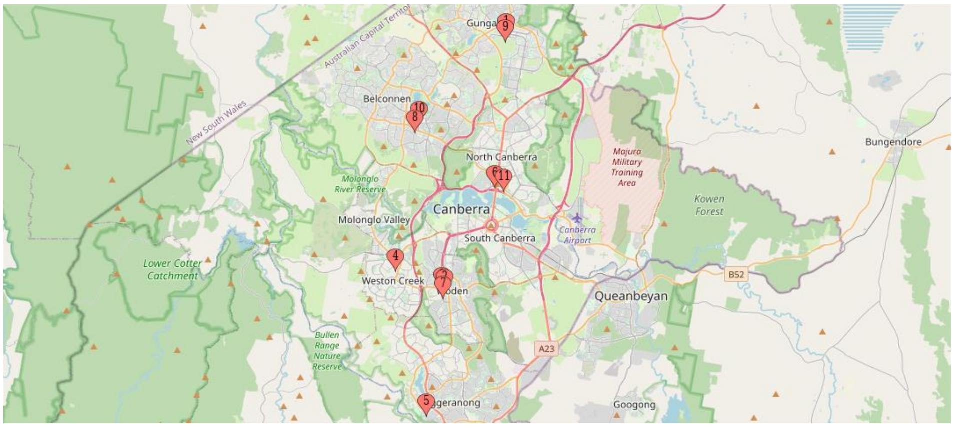
This section reports on the type and quality of data generated throughout the trial. ActewAGL supplied the data used and answered Energeia's questions as they arose. ActewAGL also acted as a liaison between JET Charge and Energeia to help resolve any further questions that arose throughout the trial.

3.1 Chargers and Buildings

While the scope of the REVS trial involved 51 chargers across 11 different sites in Canberra, data was available for only 38 total chargers, 29 of which enabled extraction of discharge data.

Four types of buildings housed EVs and chargers: government offices, health centres, the Nature Conservation Building, and the ActewAGL Building. The characteristics and number of chargers at each site largely dictated the charger installation timeframe and subsequent start date for data collection to commence. Figure 4 overlays the location of each charger on a map of Canberra.

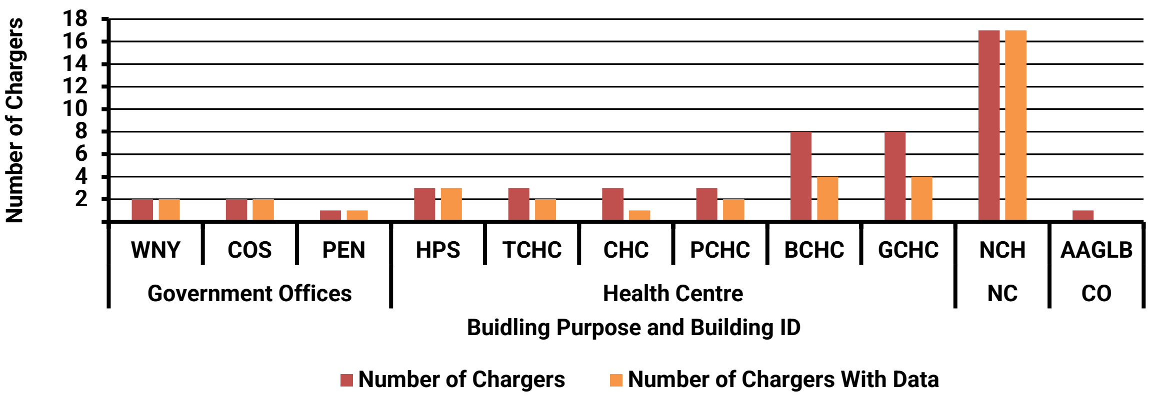
Figure 4 – Charging Site Locations in Canberra



Source: REVS Trial Data (2022), Map Customiser

Figure 5 compares the number of chargers with and without data, per building. The chargers were commissioned progressively throughout 2022, with many chargers only recording data for a few months. Installation delays diminished the amount of charger data, and the number of chargers that could be installed varied among sites. Low voltage (LV) embedded generator sites are more complex than micro-generator sites, due to greater export limits needed for an LV site. LV sites consequently required grid protection and load balancing to respond to the greater export limits; however, that variance was peripheral to the scope of the REVS trial.

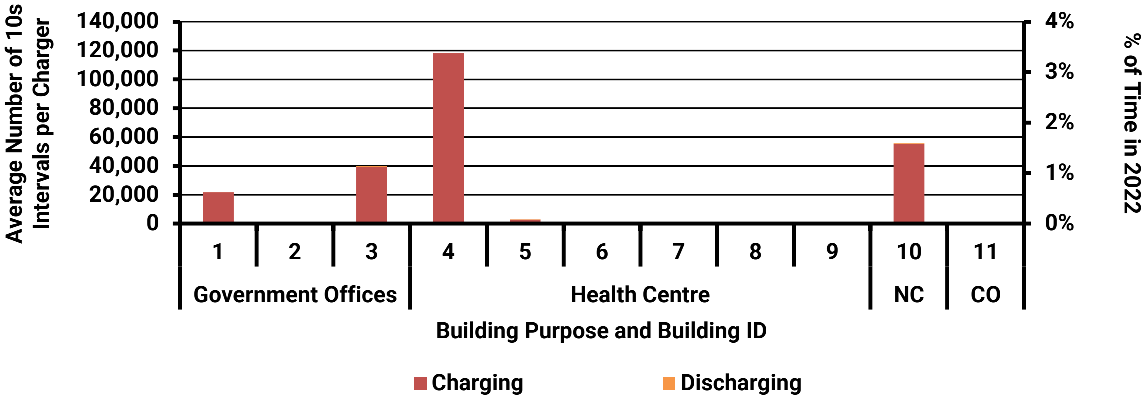
Figure 5 – Number of Chargers by Building



Source: REVS data provider email, REVS trial data (2022); NC = Nature Conservation, CO = Commercial Office

During the trial, data was recorded only when vehicles were actively charging or discharging, which precluded distinguishing whether individual vehicles were unplugged, or connected but idle. Figure 6 shows the number of intervals per charger and charging location, revealing that locations where car chargers were installed first were able to gather the most data points. While discharging data was collected, the discharging behaviour insights were less reliable, due to the small number of datapoints.

Figure 6 – Number of Intervals by Charger (With Data Only)



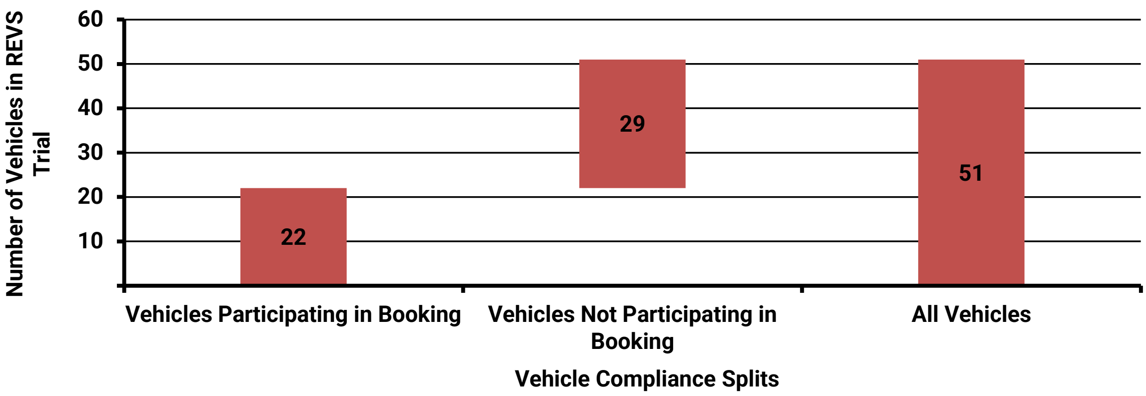
Source: REVS Trial Data (2022)

The lengthy charger installation period at each location created unforeseen delays in beginning the REVS trial. Some sites had multiple chargers, which resulted in longer installation times and subsequently reduced the number of data points that were collected from these locations. Furthermore, LV buildings required grid protection and load balancing, causing further data collection delays.

3.2 Vehicle Booking System

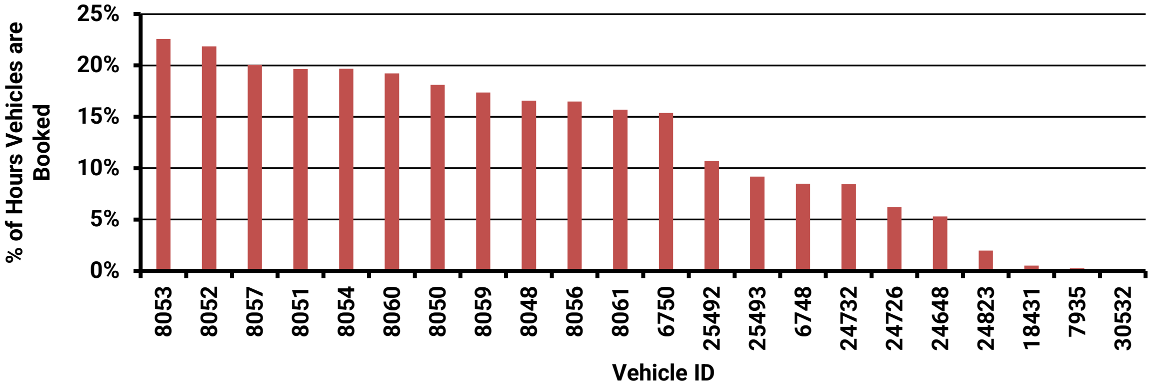
The REVS trial used a vehicle booking system in which EV owners were able to book times when the cars would be in use, and unavailable for participation in FCAS markets. This meant that, for example, if a car was booked for 20% of the year, it could be plugged in for as much as 80% of the year and able to participate in grid frequency services. Figure 7 depicts SG Fleet data comparing the number of vehicles participating in booking with those not complying, and Figure 8 presents the percentage of time booked for each of 22 vehicles.

Figure 7 – Participating Vehicles



Source: REVS Trial Data (2022)

Figure 8 – Bookings by Vehicle



Source: REVS Trial Data (2022)

Average usage throughout the trial was 12% among the 22 vehicles for which booking data was available. Non-participating vehicles were assumed to be in use from 8am to 5pm. This low booking rate among participants in the trial required a significant amount of estimation of vehicle availability.

4. Charging Session Insights

This section reports on the insights gained from the charging and discharging data of EV chargers collected throughout the REVS trial.

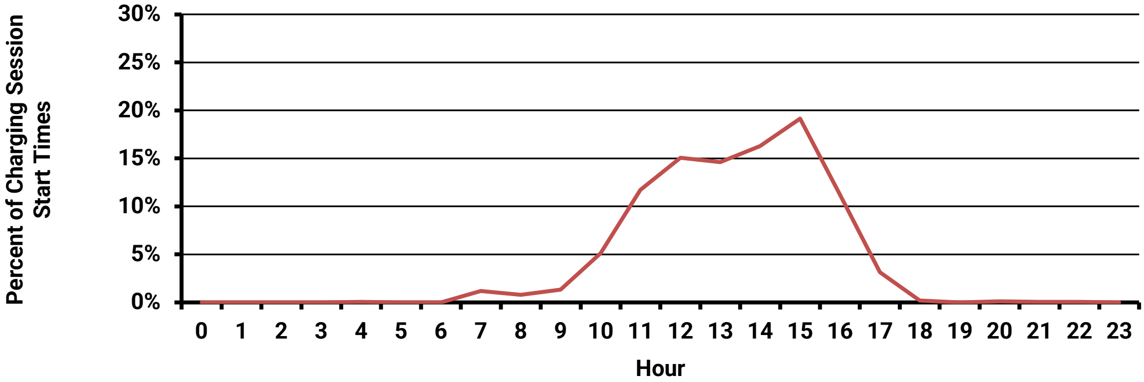
This data explicates the charging behaviour of these commercially used vehicles, including session start times, SOC, power and energy consumption, and load profiles. These insights and analyses on the behaviours and habits of EV owners were used to determine the potential amount of available capacity or spare capacity from participating vehicles. The data was on the availability to discharge or charge through V2G was used to bid into the FCAS market at specific times (as discussed further in Section 5).

The data yields important insight into the typical charging behaviour of EVs in a 9am–5pm commercial setting, contributing to this growing field of literature.

4.1 Session Start Times, State of Charge – Charging

Charging session data indicated the time of day when a charging session would commence and the vehicle's state of charge. From the available charging data collected, a total of 2,206 charging sessions took place, with the distribution of charging session start times shown in Figure 9. It shows that the majority of charging sessions occur between the hours of 10am and 5pm, which aligns with the operating hours of the commercial buildings at which these charging sites are located.

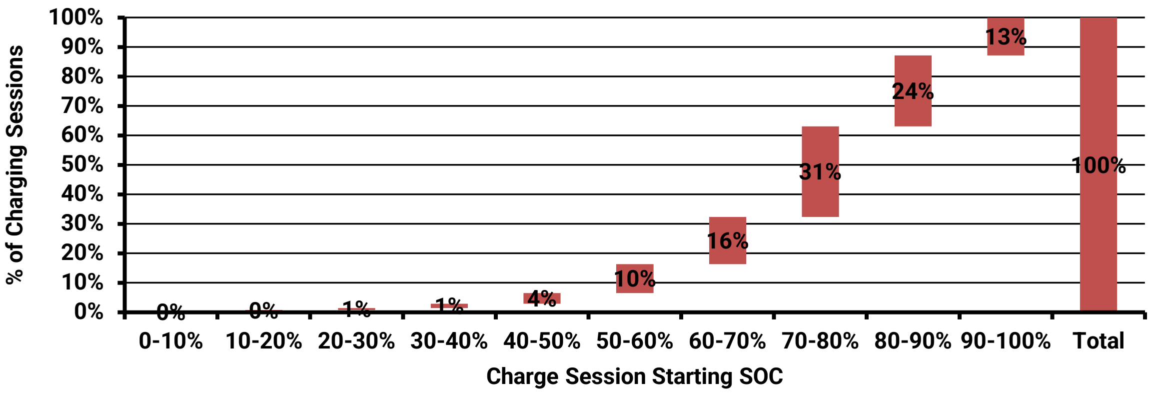
Figure 9 – Charging Session Start Times



Source: REVS Trial Data (2022)

The distribution of vehicles' SOC at the start of a charging session also was recorded, as shown in Figure 10. This determined if these vehicles could transfer power to FCAS immediately upon being plugged in, or if power transmission had to be delayed for an interval in order to avoid battery damage.

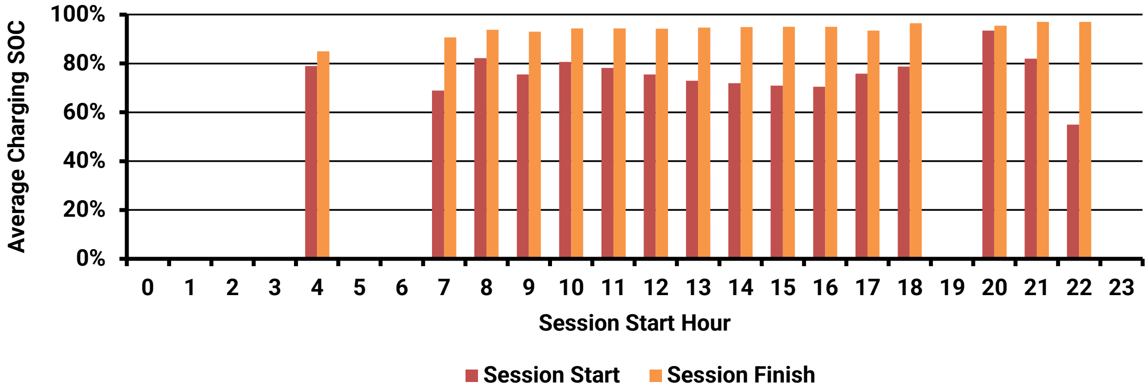
Figure 10 – Charging Session Starting SOC



Source: REVS Trial Data (2022)

The average charging session starting SOC was 74%, which implies that significant excess battery power transfer capacity typically was available for both FCAS contingency raise or lower services when a vehicle was returned to a charger. To measure whether EVs were being adequately charged by the end of a session, data was collected on the average charging session SOC at the start and end of a session, shown in Figure 11.

Figure 11 – Average Charging Session Starting and Final SOC by Hour



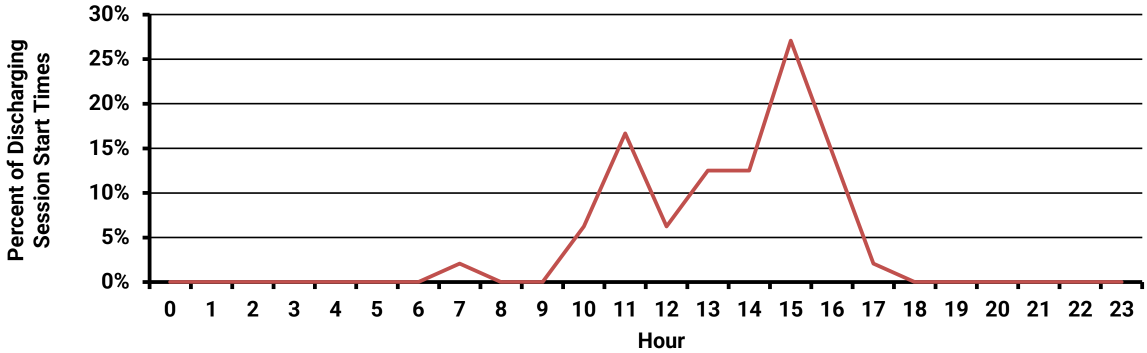
Source: REVS Trial Data (2022)

The distribution shown in Figure 11 demonstrates that the average charging session usually finished with the vehicle's SOC above 90%, meaning that the vehicles were usually fully charged. During the trial, vehicles were charged only to a maximum of 96% to leave sufficient capacity to bid into the FCAS lower market.

4.2 Session Start Times, State of Charge – Discharging

Similar charging behaviour data was collected for discharging events, with the main difference that discharging sessions were triggered by FCAS grid events rather than simply a vehicle being plugged in. A total of 48 discharging sessions were collected from the telemetry charger data, which revealed that vehicles were rarely called upon to provide contingency FCAS. Figure 12 shows that a majority of discharging session start times occurred between 10am and 5pm, aligning to the typical operating hours of the government entities. This restricted distribution time range may limit the frequency-raising grid services capabilities of commercial vehicles.

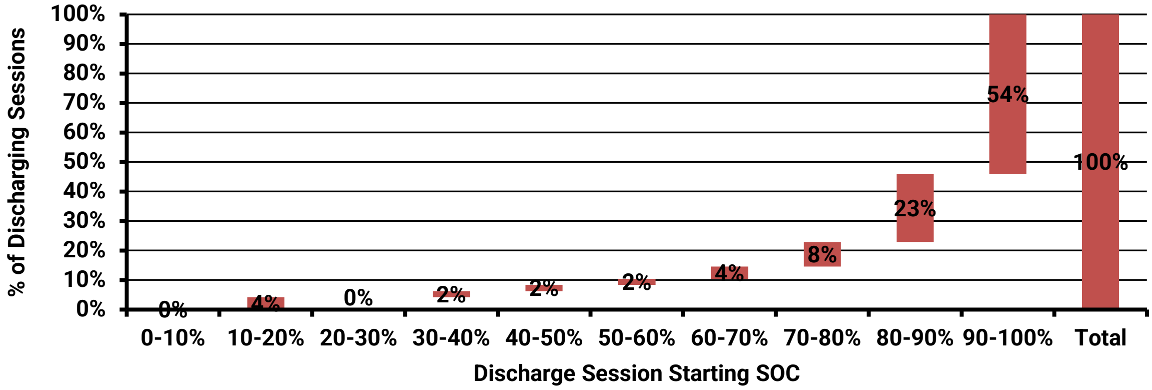
Figure 12 – Discharging Session Start Times



Source: REVS Trial Data (2022)

The distribution of discharging session starting SOC, shown in Figure 13, demonstrated that over half of the discharging sessions occurred when the SOC of a vehicle was above 90%. This indicated that most vehicles had ample capacity before participating in the FCAS raise market.

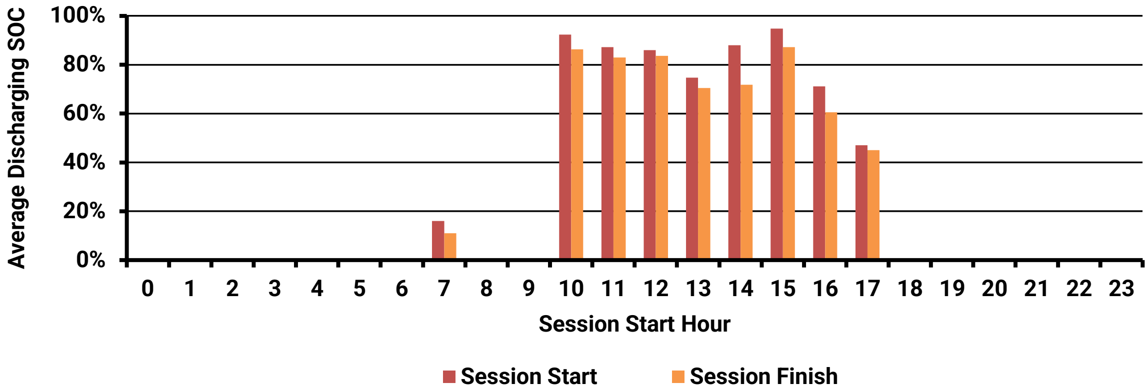
Figure 13 – Discharging Session Starting SOC



Source: REVS Trial Data (2022)

Because participation of EVs in the FCAS market may result in drainage of vehicle batteries to a low level, many EV owners may be hesitant about using their vehicles for extended or recurrent journeys requiring significant battery cycling. To investigate this concern, data was analysed on the average discharging session SOC at the start and end of a session, as shown in Figure 14.

Figure 14 – Average Discharging Session Starting and Final SOC by Hour



Source: REVS Trial Data (2022)

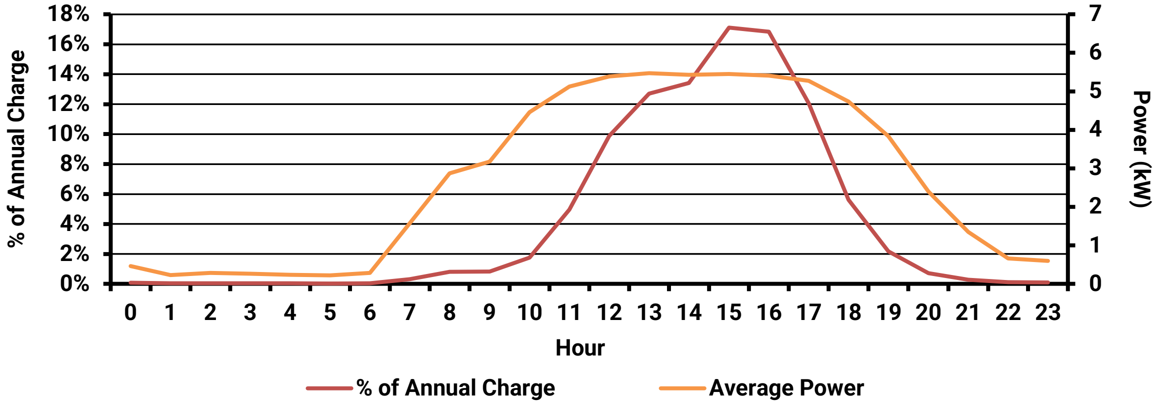
The average discharging session starting SOC was 75%, which suggested that these vehicles were not extensively used between charging locations. The data shows little difference in starting and ending SOC during grid events, suggesting that contingency events require only a small amount of energy from these vehicles – important information that should be conveyed to sceptical owners of EV fleets.

4.3 Power and Energy Consumption – Charging

Data capture in the REVS trial also included power and energy consumption to determine which hours of the day chargers were most frequently used, and if annual consumption was correlated to the average power being drawn. Throughout the trial, charging sessions were triggered when the vehicle was plugged into the charger, and during these sessions the instantaneous power being drawn was averaged and logged, along with data on the total energy that vehicles imported.

The power being drawn was limited to a maximum of 7 kW, because this was the maximum alternating current (AC) charging power of the Nissan Leaf, and these AC chargers were used in residential applications. Figure 15 illustrates the charging profile per hour, as well as the percentage of annual charge by hour.

Figure 15 – Total Trial Charging Profiles

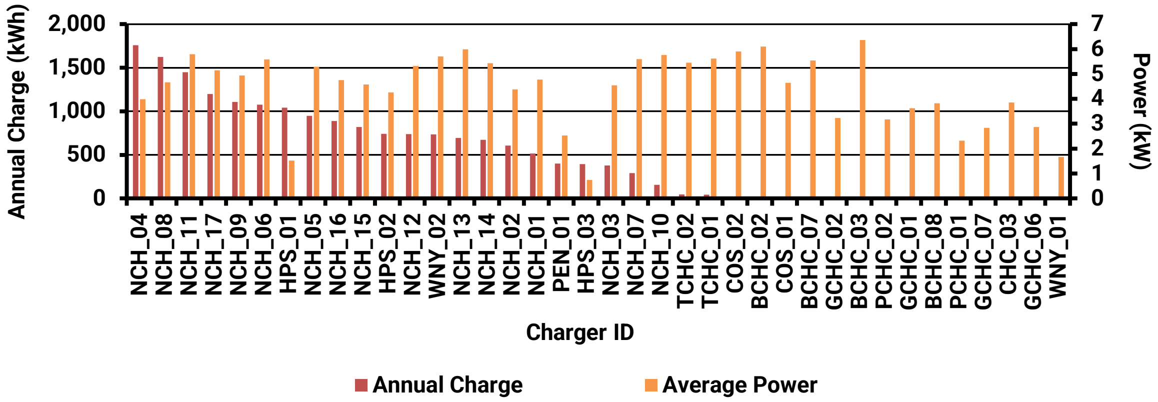


Source: REVS Trial Data (2022)

Interestingly, while the vehicle has a maximum AC charging power limit of 7 kW, during peak periods the average power hovered around just 5.5 kW. This could potentially be due to the internal technology of some EVs, which restrains the charging of their batteries to protect their longevity when their SOC falls outside the lower and upper limits of 20% and 80%, respectively.[3] Thus, the average power was reduced throughout the trial, since the SOC for a significant percentage of the vehicles remained relatively high because many were not driven far.

Figure 16, which depicts the total annual consumption and average power for each charger, reveals that many chargers were used infrequently, if at all, throughout the duration of the trial. This could indicate that the chosen commercial locations had relatively lower vehicle usage.

Figure 16 – Annual Consumption and Average Power by Charger



Source: REVS Trial Data (2022)

The total annual consumption of vehicles throughout the REVS trial was 18.4 MWh. While the annual consumption strongly correlated to the number of charging sessions, it had little correlation to average power. This is most likely due to the varied use of these EVs, which would have been consistently drawing the same amount of power from each charger during the trial but not necessarily consuming the corresponding amount of charge throughout the year.

The resulting charging profiles indicated that these vehicles were likely on an unmanaged charging schedule and did not require a great amount of time to recharge.

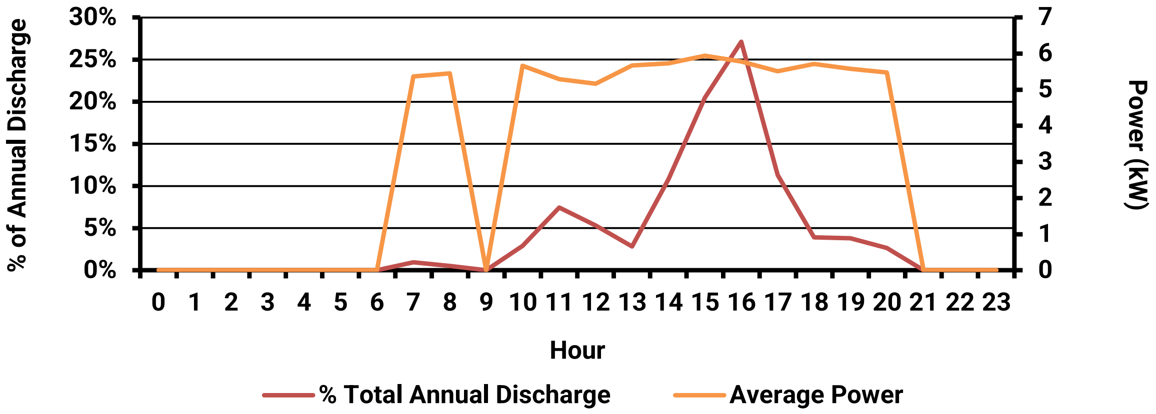
[3] Osprey Charging Network (2022) What affects your EV charging speed? Available from: https://www.ospreycharging.co.uk/post/what-affects-your-ev-charging-speed

4.4 Power and Energy Consumption – Discharging

Power and energy consumption data also was recorded for discharging events to measure how much electricity was being discharged from participating vehicles during grid events. This was a key factor to consider in the trial, because EV owners could become apprehensive about participating in grid frequency control if FCAS events were consuming too much energy from their vehicles. This could result in their vehicles lacking sufficient charge to complete longer journeys.

Furthermore, depending on the frequency of these FCAS events, recurrent battery drainage could approach recharge cycle limits and thereby shorten the life span of vehicle batteries. Figure 17 shows the total trial charging profile and percentage of annual charge by hour to illustrate when FCAS raise events occur.

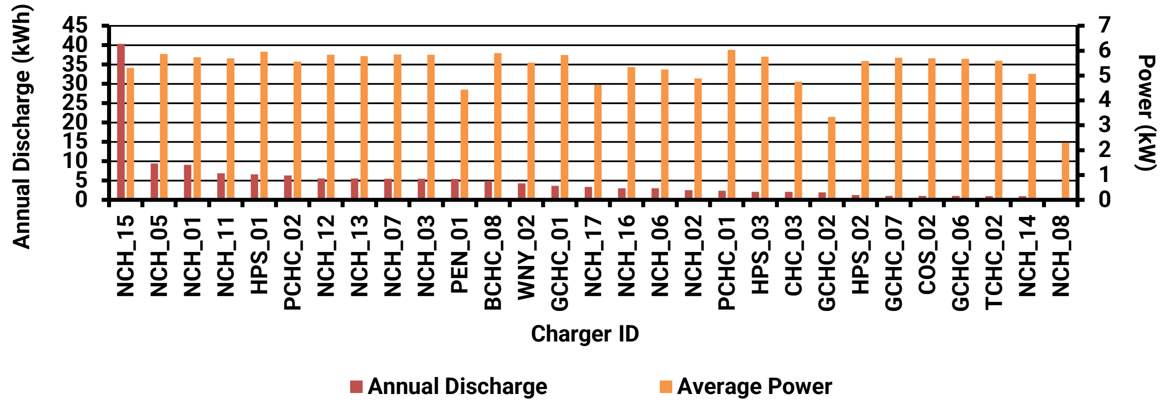
Figure 17 – Total Trial Discharging Profiles



Source: REVS Trial Data (2022)

These profiles indicate that FCAS raise events were most common between 2pm and 5pm, with a peak occurring at 3pm. Figure 18 reveals the annual discharge and average power by charger during discharging events, constituting the total amount of energy used during these FCAS events.

Figure 18 – Annual Discharge and Average Power by Charger

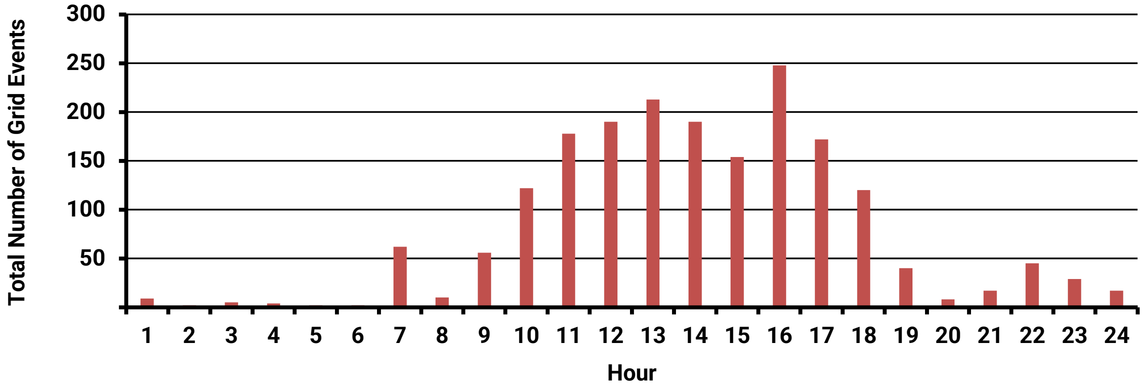


Source: REVS Trial Data (2022)

During the REVS trial, the recorded total annual discharge from all the vehicles was 0.146MWh, or 0.79% of the total amount of energy used for charging the vehicles. This verifies that the number of FCAS events requiring energy to be drawn from EV batteries was minimal, suggesting low risk of premature battery degradation for EV owners participating in FCAS services.

Figure 19 shows the number of grid events for hourly start times throughout the day. Not all grid events represented an FCAS event. Each event simply indicated that the frequency had fallen out of the safe operating limits, which could be rectified by either a contingency or regulation FCAS event, depending on the scale of the fluctuation.

Figure 19 – Number of Grid Events by Start Times

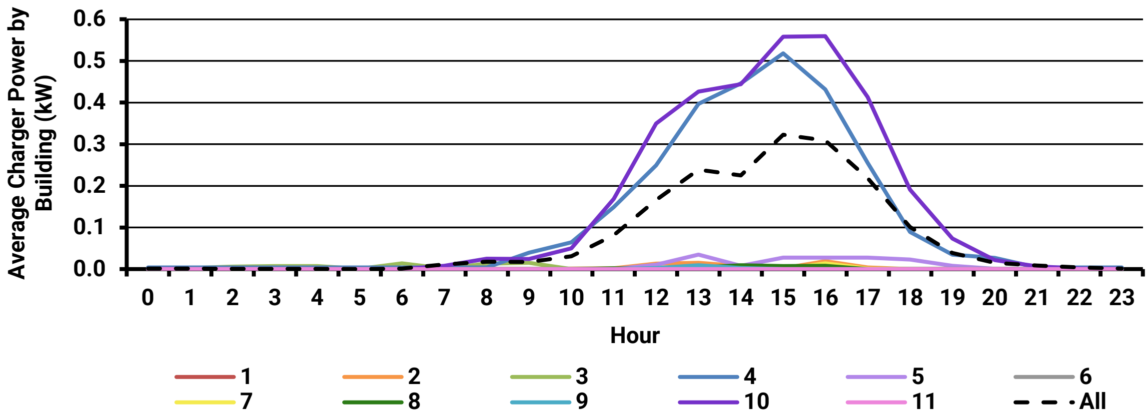


Grid events commonly occurred during the afternoon hours, corresponding to most discharge events, a time of day when vehicle availability to provide grid services may be limited. Few FCAS raise grid events occurred at night when most of these vehicles would be available to discharge, after their usual operating hours.

4.5 Load Profiles by Day Type – Charging and Discharging

To help determine the charging and discharging patterns of participating EVs in the trial throughout the week, load profiles were collected for each building on weekdays. Figure 20 shows the average weekday charging profiles for each of the buildings and identifies the times when charging and discharging most occurred.

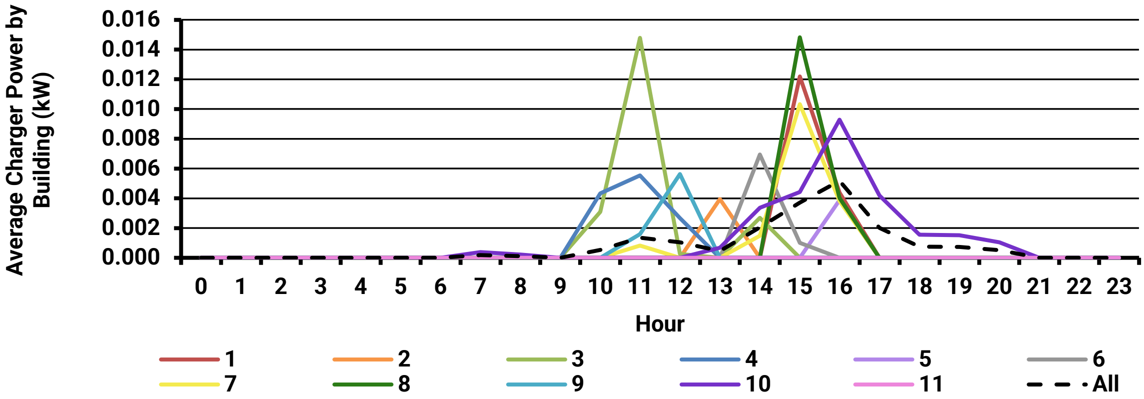
Figure 20 – Average Weekday Charging Profile by Building



Source: REVS Trial Data (2022). Note: Each number in the legend indicates an individual charger.

These results corroborated previous findings which showed that for most buildings, charging was done relatively infrequently and for short periods of time given the average charger power. The average charging profile (indicated by the black dashed line) for all chargers that yielded data shows a small peak at 1pm and a larger peak around 4pm, presumably aligning with the return of employees and their vehicles from daily trips before the business closes for the day. The average discharging profiles during weekdays, shown in Figure 21, illustrated when grid services drew most heavily from EVs.

Figure 21 – Average Weekday Discharging Profile



Source: REVS Trial Data (2022), Note: Each number in the legend indicates an individual charger.

The discharging profiles differ from the charging profiles primarily because they are dictated by grid events rather than simply charging when a vehicle is plugged in. Moreover, the discharging profiles exhibit frequent and distinct peaks due to the unpredictable nature of these FCAS events. The average discharging profile was relatively flat throughout the day with a noticeable peak around 4pm, which aligns well with the high number of grid events that occur at this time (see Section 4.2).

Nearly all charging occurs on weekdays, with only 1% of charging sessions on weekends, attributable to the weekday-only operation of these commercial premises with chargers installed. Accordingly, vehicles in the trial did not participate in FCAS on weekends.

5. V2G Benefits

This section reports on the potential monetary benefits for EV owners who participate in the FCAS market through V2G, for which the REVS project findings serve as a case study.

This data from the project afforded insights into the EV capacity to sustain grid services throughout the day to provide. This determined how much revenue these vehicles could potentially earn through participation in each of the contingency FCAS markets (FCAS raise and FCAS lower).

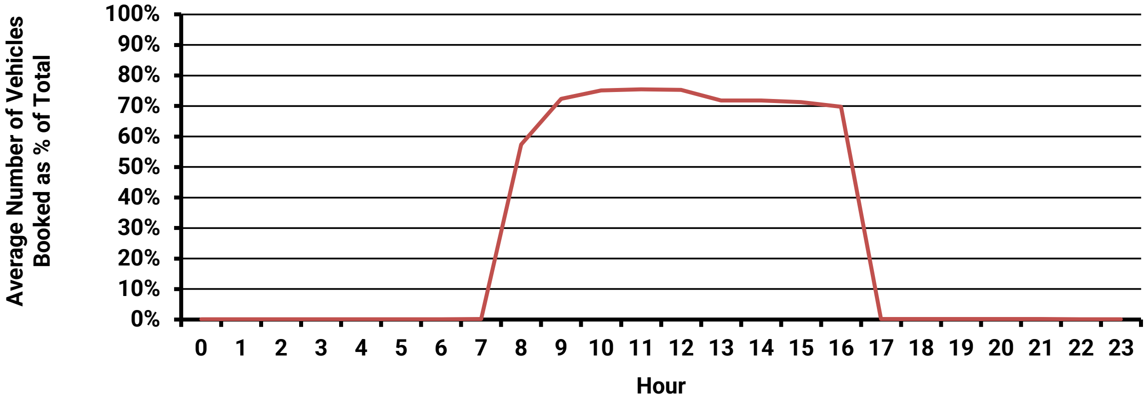
5.1 FCAS Raise V2G Capacity

The FCAS raise market makes use of standby dispatchable capacity to respond to unexpected frequency events or fluctuations as a means of ensuring that the grid remains within its safe operating frequency. The nature of these frequency events makes batteries well suited to respond to grid demands with speed and stability.

One of the main objectives of the REVS trial was to monitor the availability of vehicles throughout the day to determine if they could be used as a reliable source for these frequency services while they are idle. The trial accomplished this by implementing a booking system that reserved vehicles for use (thereby rendering them unavailable for FCAS) one day in advance and allowed the operator to estimate their available idle capacity for bidding into the FCAS market.

Figure 22 shows the percentage of vehicles in the trial unavailable for FCAS services over the course of the day, reflecting how many vehicles were away from the charger at each hour of the day, and therefore how much remaining idle capacity could be bid into the FCAS market at those specific hours of heavy vehicle driving use.

Figure 22 – Percentage of Vehicles Unavailable for FCAS by Hour

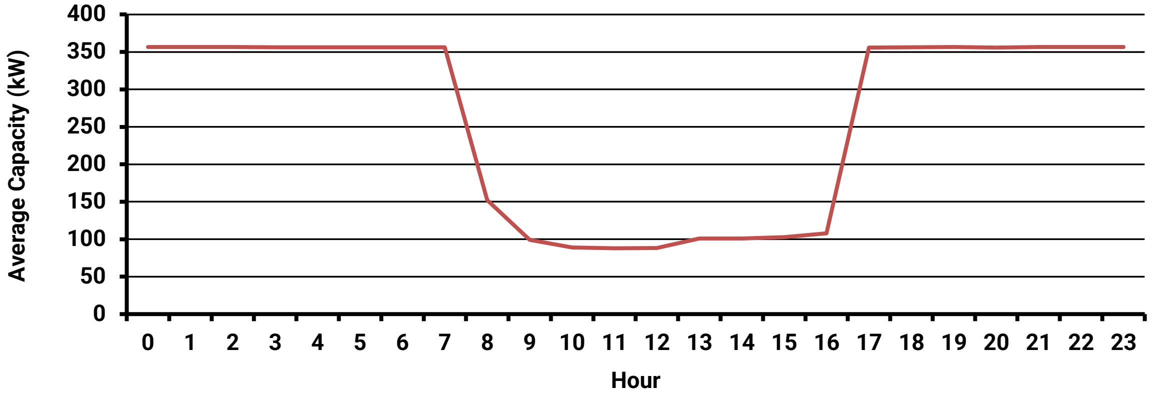


Source: REVS Trial Data (2022)

The trial data showed that vehicles were generally in use from 8am to 5pm weekdays. During this peak window, capacity for frequency services was limited to only one third, as most vehicles were in use and therefore unable to provide FCAS raise services. Vehicles that were not participating in the booking system were assumed to be unavailable to provide grid services during business hours.

The FCAS raise potential from the remaining idle vehicles, shown in Figure 23, indicated the capacity of the vehicles that were plugged in and awaiting FCAS requests at certain hours of the day. Because this available capacity corresponds to the number of available vehicles that are plugged in, its shape is the inverse of the graph for unavailable vehicles for FCAS (Figure 22).

Figure 23 – Average FCAS Raise Capacity by Hour (7 kW per Car)

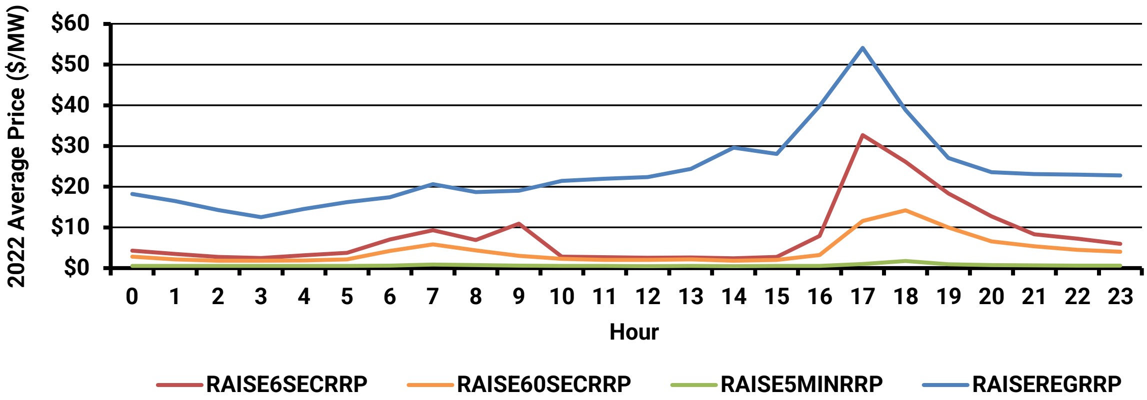


Source: REVS Trial Data (2022)

During peak vehicle usage, FCAS raise capacity was limited to less than 100 kW on average, with the maximum FCAS potential peaking at 357 kW. The FCAS raise capacity was calculated from booking numbers of participating and non-participating vehicles, as well as the power per vehicle. The assumption for this study was that each vehicle available had FCAS raise capacity of 7 kW, reflecting the size of the charger.

The availability capacity at the time interval of the trial period was then multiplied by the corresponding 2022 New South Wales (NSW) FCAS raise price, shown in Figure 24, to calculate the potential revenue from bidding the idle capacity into the FCAS market.

Figure 24 – Average NSW FCAS Raise Price by Hour



Source: NEMOSIS (2022)

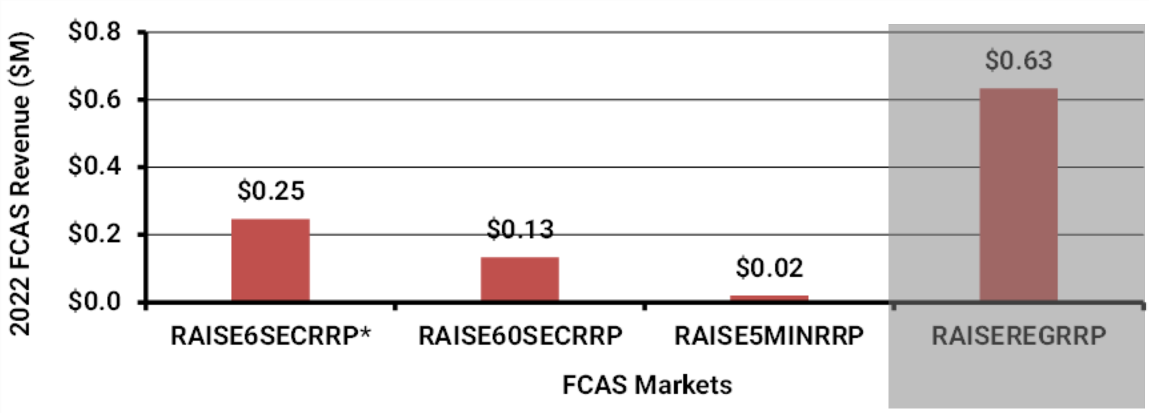
FCAS prices in 2022 typically peaked in late afternoon, which aligned well with vehicle availability, because most vehicles were returned by this time to charge overnight. This analysis indicates high revenue potential from using idle capacity of plugged-in EVs for FCAS raise services, which is discussed in the following section.

5.2 Potential V2G Revenue per Vehicle – FCAS Raise

Idle EV capacity presents an opportunity for EV owners to earn revenue by bidding into the FCAS markets through V2G, thereby making use of their vehicles when they are plugged in and available. This provides an incentive for EV owners to participate in the FCAS raise market. Figure 25 delineates the total potential revenue that could be earned by participating in either of the FCAS raise markets.

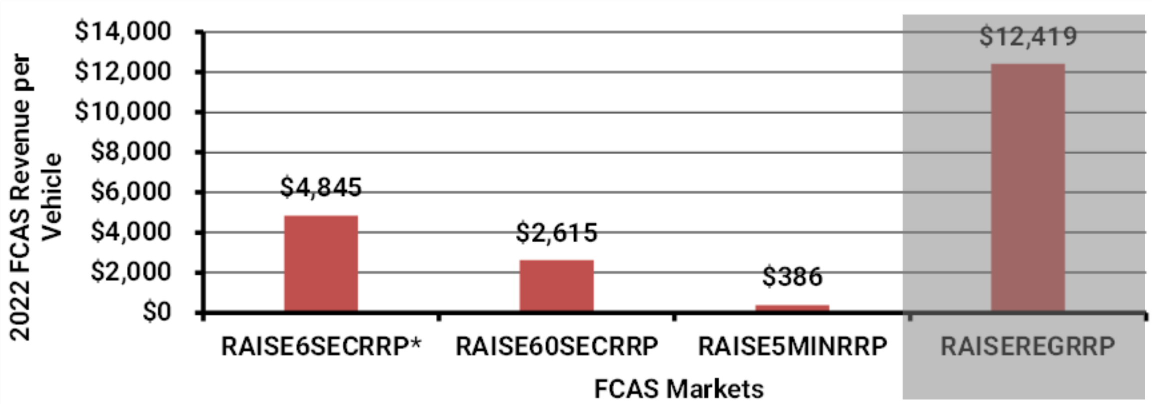
Figure 26 shows the total potential revenue per vehicle. FCAS revenue was calculated based on vehicle availability from trial data, historic FCAS price per interval in 2022, and an assumed vehicle capacity of 7 kW.

Figure 25 – Total Potential FCAS Raise Market Revenue from Trial (2022)



Source: REVS Trial Data (2022), NEMOSIS (2022), Energeia (2023)
*V2G was not legally allowed to bid into this market in the REVS trial

Figure 26 – Potential FCAS Raise Market Revenue per Vehicle (2022)



Source: REVS Trial Data (2022), NEMOSIS (2022), Energeia (2023)
*V2G was not legally allowed to bid into this market in the REVS trial

The contingency FCAS results indicate that V2G could potentially be earning thousands of dollars per vehicle in the FCAS market, with the prospect for much higher profits if more powerful chargers were utilised. This would raise the capacity ceiling, which can be bid into the FCAS market (e.g., if the discharge capacity were increased to 15 kW, the 60-second raise revenue per vehicle would increase to $5,604). While EV batteries are technically capable of dispatching at the response times required for 6-second contingency FCAS market participation, behind-the-meter technology is not yet legally allowed to participate in this market due to ramping constraints in the AS/NZS 4777.2:2020.[4]

The regulation FCAS (highlighted by the grey box) results demarcate an upper boundary of what could be earned on the FCAS market. While regulation FCAS had the greatest potential for profit, it was not considered for this trial because the wear and tear of the frequent battery charging/discharging that participating in this market requires makes the use case much less feasible than bidding into contingency markets.

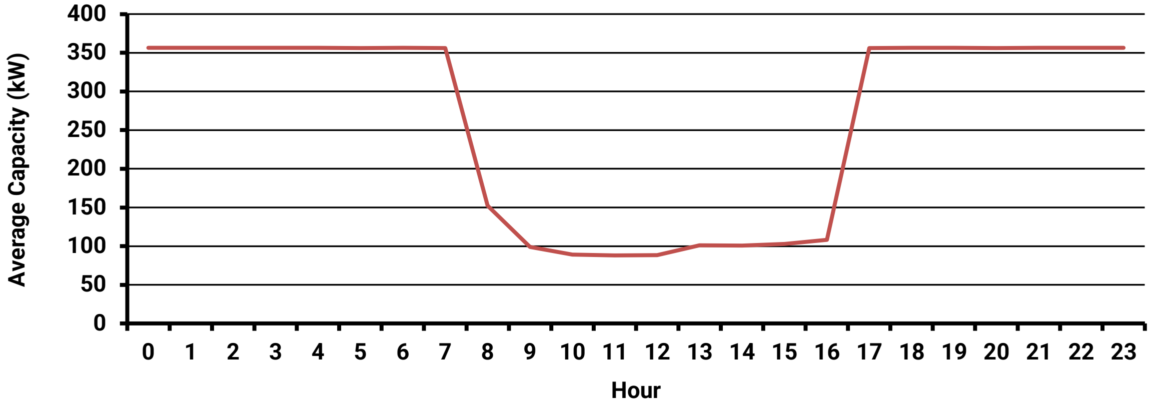
While these results seem appealing for EV owners, consistent participation may potentially result in premature battery degradation. For this reason, the above results are indicative only of the potential revenue an EV owner could earn. They are less realistic for individuals who rely on their vehicles every day at varying and unpredictable hours and therefore may not have them available to participate in FCAS markets.

[4] Haque et al. (2022), Lessons Learnt Certification and Performance of Charger against AS4777.2:2022 Standard: Insights from the Realising Electric Vehicle-to-grid Services (REVS) trialhttps://arena.gov.au/assets/2022/05/realising-electric-vehicle-to-grid-services-lessons-learnt-2.pdf

5.3 FCAS Lower V2G Capacity

The FCAS lower market involves managing excess electricity supply by making use of spare capacity to rectify frequency deviations in the grid. Batteries also make excellent candidates for the FCAS lower market, because they can absorb excess electricity when not at full capacity, thereby helping maintain grid stability. As previously mentioned, the trial enabled determination of the available capacity of the vehicles using a booking system, and estimation of the amount of spare capacity. The percentage of cars unavailable to participate was the same as in Section 5.1, with the lower capacity potential from these idle vehicles shown in Figure 27.

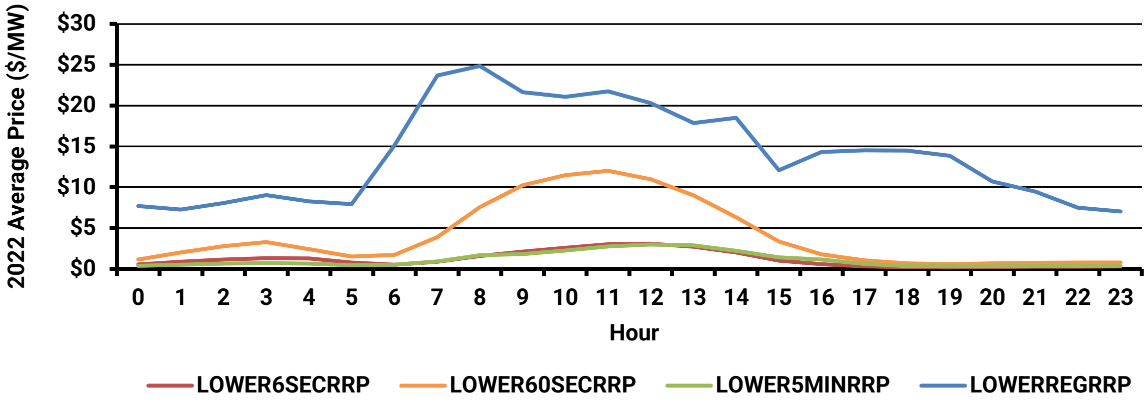
Figure 27 – Average FCAS Lower Capacity by Hour (7 kW per Car)



Source: REVS Trial Data (2022)

The FCAS lower capacity was based on the SOC and the number of cars in the charging session data, as well as the 40 kWh battery capacity of the Nissan Leaf. To enable participation in FCAS lower markets, the SOC in the REVS trial was capped at 96% in order to retain 1.6 kWh of spare capacity from each vehicle. The FCAS lower prices, shown in Figure 28, were significantly less than the FCAS raise prices, because FCAS raise services are more complex and costly to operate than FCAS lower services. The reason is that FCAS raise requires generators to turn on and have extra resources on standby, whereas FCAS lower does not require any standby resources and can be activated by simply turning on a load.

Figure 28 – Average NSW FCAS Lower Price by Hour



Source: NEMOSIS (2022)

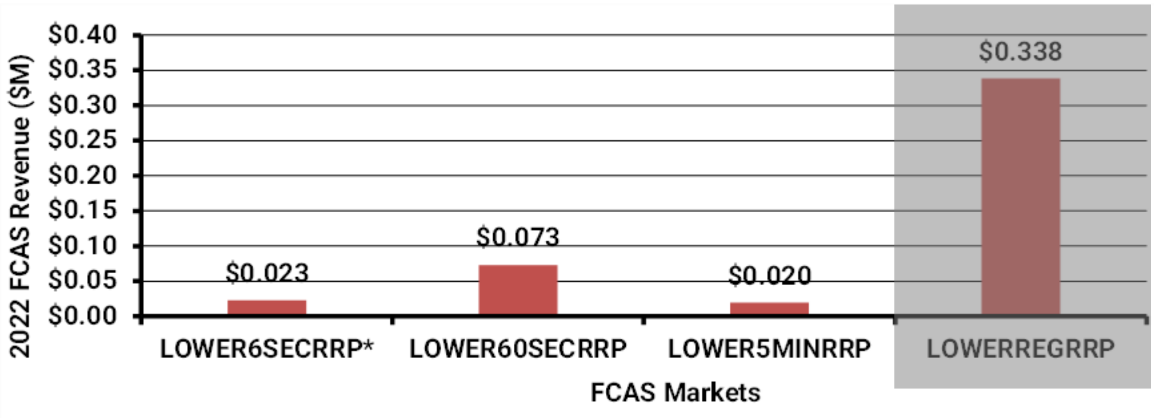
5.4 Potential V2G Revenue – FCAS Lower

Available EV capacity similarly represents an opportunity for EV owners to earn revenue by bidding their spare capacity into the FCAS market, thereby making use of their vehicle's non-fully charged battery when not in use. While the FCAS lower prices are not as appealing, an incentive exists for EV owners to allow the grid to make use of their spare capacity when an excess supply of electricity exists.

Data from the trial in which vehicles were charging was present only in about 20% of the 5-minute intervals. For cases in which no charger data was present, booking data was used as a substitute to determine the number of cars plugged in, with an assumed SOC of 96% when cars were idle. Figure 29 shows the total potential revenue earned from the FCAS lower markets. The difference in 5-minute FCAS prices was the main driver behind the varying revenues across the FCAS raise and lower markets.

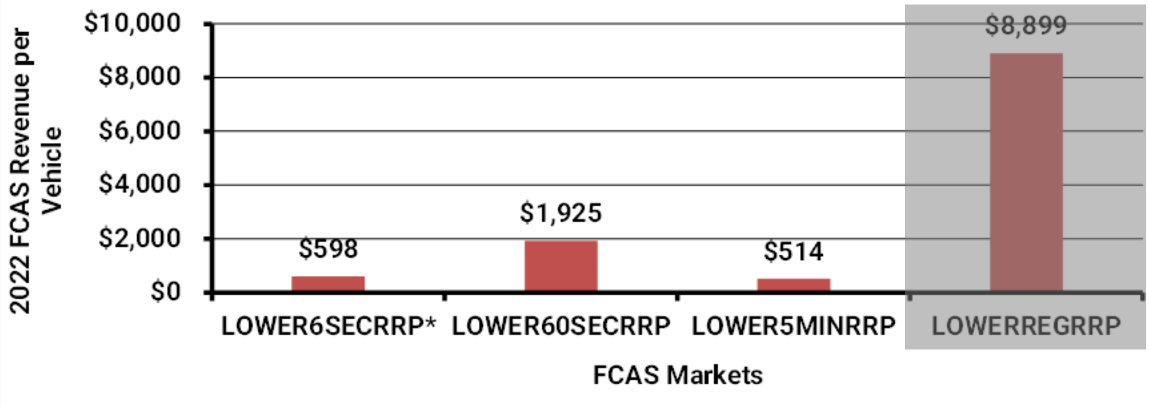
Figure 30 shows the total potential revenue per vehicle, breaking down the above values into potential revenue per vehicle in the trial.

Figure 29 – Total Potential FCAS Lower Market Revenue from Trial



Source: REVS Trial Data (2022)
*V2G was not legally allowed to bid into this market in the REVS trial

Figure 30 – Potential Revenue FCAS Lower Market per Vehicle



Source: REVS Trial Data (2022)
*V2G was not legally allowed to bid into the LOWERREGRRP market in the REVS trial

As with FCAS raise, FCAS lower also has the potential to be a viable revenue stream in the commercial context, with the average vehicle in the trial able to earn just under $2,000 in the 60-second response market. Consistent participation of single vehicles in faster markets could lead to premature battery degradation, making these potential revenues much less realistic for an everyday EV driver. Participating in the FCAS lower market would require tighter management of a vehicle's charging to ensure capacity to charge the vehicle in response to a lower signal.

5.5 Conclusion

It is clear from the REVS trial data and the above analysis that using V2G to provide FCAS to the grid has the potential to become a lucrative and cost-effective way for vehicle fleet owners to subsidise incorporation of EVs into their fleet. The pragmatic application of V2G technology requires strategic and attentive management. Rapid growth and increasing popularity of V2G technology in the future may lead to oversaturation of the FCAS market as a result of abundant EV battery (and other consumer energy resource) capacity, which would make participating in these FCAS markets less appealing to EV owners and aggregators.

Appendix A – About Energeia

Energeia, which was founded in 2009, has grown to become one of the largest specialist energy consultancies in Australia. Energeia has analytical, advisory and technical services expertise in the following areas:

- Energy policy and regulation
- Smart networks and smart metering
- Energy storage
- Electric vehicles and charging infrastructure
- Distributed generation and storage technologies
- Network planning and design
- Demand management and energy efficiency
- Energy product development and pricing
- Wholesale and retail electricity markets.

Energeia delivers its services across three lines of business:

- **Proprietary Research** – We produce in-depth reports on distributed energy resources (DER) related markets and technologies of strategic interest, including EVs, solar photovoltaic (PV) and storage technology, smart grids, microgrids, energy efficiency, and home energy management
- **uSim and wSim Utility and Market Simulators** – We have developed industry-leading utility simulation software that models customer behaviour, bills, DER adoption, 17520 load profiles, utility sales, capex, opex, rates and financial performance, on an integrated basis
- **Professional Services** – We offer tailored services in the areas of rate and incentive design, cost of service analysis, DER and load forecasting, system planning, and DER technology-related strategy and plan development.

We are organised into research, consulting, and software development functional units with significant crossover between the working groups through the significant quantitative analyses that we perform on behalf of our clients, much of which requires custom tooling.

- The consulting and research team is responsible for delivering Energeia's proprietary research reports and professional services.
- The software development working group is responsible for the development of our utility simulation tool, uSim

Energeia's industry specialists are empowering the energy sector by excelling in advanced research and consultancy services focused on electricity

Heritage

Energeia was founded in 2009 to pursue a gap that we foresaw in the professional services market for specialist information, skills, and expertise that would be required for the industry's transformation over the coming years.

Since then, the market has responded strongly to our unique philosophy and value proposition, geared towards those at the forefront and cutting edge of the energy sector.

Energeia, with its focus on emerging opportunities, has been instrumental in advancing landmark projects and transforming the industry by devising practical solutions for complex problems.

Energeia Pty Ltd

Level 1
1 Sussex Street
Barangaroo NSW 2000

+61 (0)2 8097 0070
energeia@energeia.com.au
energeia.au

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