CHARGEFOX

Rapid DC Time-of-Use Pricing

Chargefox Smart Charging Trial

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Executive summary

Overview

With funding from the South Australian Department of Energy and Mining's Smart Charging Trial program, Chargefox installed a new metropolitan DC fast charging station at Port Adelaide Plaza. The station became operational on **December 6, 2022**.

Using purpose-built functionality in the Chargefox app as well as customised, enhanced data analysis capabilities, we conducted a series of pricing experiments at the station to explore the relationship between driver behaviour and the price of charging.

Our objective was to explore whether time-of-use pricing strategies are effective at encouraging drivers to shift their consumption to 'solar sponge' periods in the middle of the day, where solar energy is abundant and wholesale energy prices are at their lowest.

Our central question was:

Will changing the price of fast, high-powered DC charging influence driver behaviour in any way? If it does, how? And why?

Research cohort

Who are Australia's current electric vehicle owners?

Research suggests[i] that the majority of current electric vehicle owners in Australia:

- are 35 - 44 years of age or older;
- identify as male;
- live in detached housing with off-street parking, and
- have higher-than-average combined gross household incomes.

Electric vehicle sales data suggests that the majority of electric vehicle drivers belong to the 'innovator' or 'early adopter' category of consumer: these consumers are willing to trade the perceived risks associated with a new technology for the opportunity to participate in the technology's maturation.

This profile is changing, however: we are seeing the 'early majority' consumer enter the electric vehicle market. This 'early majority' cohort is more diverse and, while open to change, requires new technologies to present clear, tangible and immediate benefits.

Who charges their electric vehicles at Port Adelaide Plaza?

According to Australian Automotive Association data, electric vehicle ownership in the suburb of Port Adelaide is limited, with only 11 battery electric vehicles (BEV) currently registered to addresses within the postcode.[ii] Drivers who charge at Port Adelaide Plaza are more likely to live and/or work outside of the suburb – inferring that they are either making a deliberate trip to shop and/or charge in Port Adelaide, or are passing through the suburb to other destinations.

As a consequence, drivers who charged at the Port Adelaide Plaza charging station over the course of this trial were likely to:

i Patricia Sauri Lavieri, Gabriel Jurado Martins de Oliveira, *Planning for the majorities: are the charging needs and preferences of electric vehicle early adopters similar to those of mainstream consumers?*, Oxford Open Energy, Volume 2, 2024, oiad001, https://doi.org/10.1093/ooenergy/oiad001

ii Data sourced from the Australian Automobile Association's Electric Vehicle Index website at https://data.aaa.asn.au/ev-index/

- broadly represent the demographic profile of current Australian electric vehicle drivers
- be ‘innovator’ and ‘early adopter’ consumers, with a minority being in the ‘early majority’
- live outside the suburb of Port Adelaide

Over the course of this study, we also identified two attitudinal segments within the above cohort: **‘need to charge’** and **‘want to charge’** drivers. Each segment has a unique set of needs and priorities, and consequently interprets and responds to pricing differently.

Research approach

We implemented three experiment cycles, with each cycle running for a duration of two months.

In each cycle, we applied a time-of-use pricing strategy, with per-kWh pricing set at its lowest during the ‘solar sponge’ period (9am - 4pm).

We varied the per-kWh price and pricing construct in each cycle to observe whether changes to charging behaviour occurred.

We captured, analysed and compared charge session data across experiment cycles, specifically focusing on:

- the **number of charge sessions** initiated within the cycle’s defined time periods
- **total consumption** within defined periods
- median **consumption** per charge session
- median **charge session duration**
- the median **cost-to-driver** of a charge session
- median and total **revenue generated for the site host**

To ensure we were not detecting seasonal or other network-wide effects, we compared usage data from Port Adelaide Plaza against other comparable charging stations on the Chargefox network.

We also had access to footage from a close-caption television (CCTV) camera installed onsite. This allowed us to capture:

- the **number of queuing events** per defined time period
- the median **duration of queueing events** per period
- the number of **ICEing** events per period

Camera data helped us understand the context of charging at the station and allowed us to track increases and decreases in charging demand over the trial period.

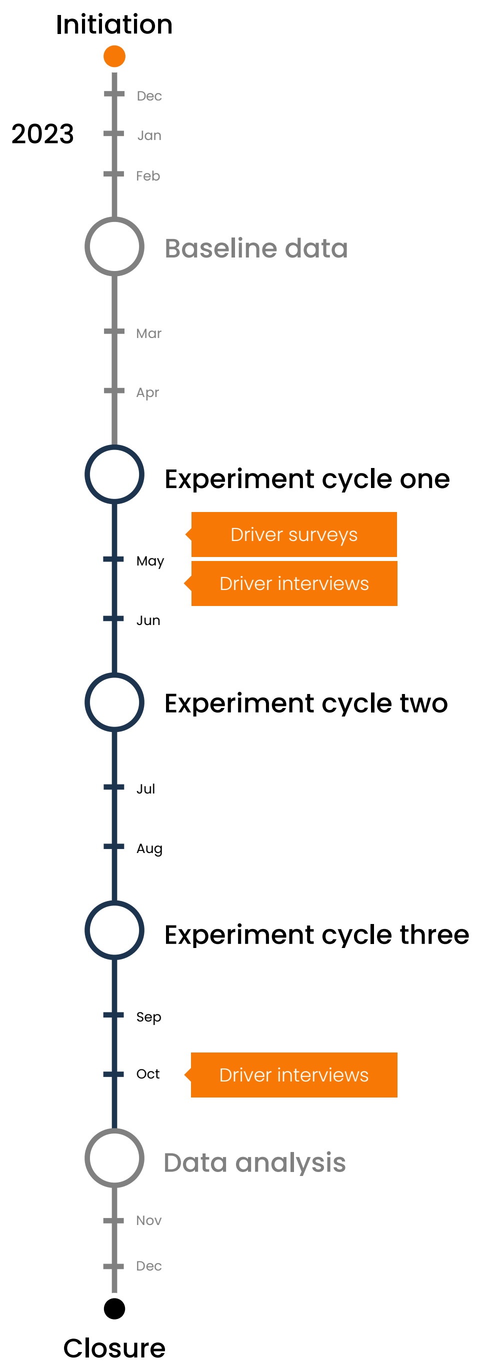


Fig i. Research activity timeline

Key findings

Time-of-use pricing can have a **limited but tangible effect** on charging behaviour.

The results of our study indicate that **time-of-use price signals may be effective** at encouraging electric vehicle drivers to consolidate their use of public charging stations to periods of peak renewable energy generation. There are a number of caveats, however.

We believe that price signals are only effective when:

- a **per-kWh pricing strategy** is applied to the station, rather than a per-minute pricing strategy;
- the pricing strategy is **simple and easy for a driver to understand**, with limited pricing 'facets' and a noticeable gap in price between time periods;
- the pricing strategy aligns with a driver's **'price of charging' mental model** (see below);
- the pricing strategy falls within a driver's **'goldilocks zone' of pricing** (see below);
- the charging station to which the pricing strategy is applied meets or exceeds **other desirability criteria**, e.g. availability, reliability, speed, convenience; and
- the charging station is **frequented by a majority of 'want to charge'** drivers, rather than 'need to charge' drivers (see below).

'Need to charge' vs 'want to charge' drivers

Two attitudinal segments emerged in our study: drivers who '**need to charge**' and drivers who '**want to charge**'.

Drivers who 'need to charge' are **extrinsically motivated** to charge in public: factors outside of their control are compelling them to use a public charging station.

Drivers who 'want to charge' are **intrinsically motivated** to charge in public: they have the range (in km) and flexibility to choose where, or whether, to charge.

We believe 'want to charge' drivers are more likely to respond to a price signal, as 'need to charge' drivers will prioritise the preservation of mobility over any consideration of price.

'Reasonable' pricing: a driver's pricing mental model

EV drivers evaluate per-kWh charging rates by determining whether they are commensurate with their home energy rate, plus a 'reasonable' margin that covers the cost of infrastructure, plus a 'convenience premium' that applies to 'fast' charging stations.[iii]

Home energy rate
What I pay for energy at home, per kWh, excluding daily service charges

+

Infrastructure margin
What I imagine it costs to install and maintain a charging station

+

Convenience premium
Fee for the ability to charge faster and/or more conveniently

iii 'fast' is broadly defined as a charging station capable of fully charging a vehicle in less than an hour, as per the Electric Vehicle Council of Australia's definition of a 'Level 3 / Mode 4' charging station: https://electricvehiclecouncil.com.au/a-z-charging/

The 'goldilocks zone': pricing that's 'just right'

EV drivers set both an upper and lower limit on the price of charging when it comes to what they believe is 'reasonable'.

Pricing that approaches the per-litre price of petrol is considered 'too high' and is seen as 'price gouging.' Drivers in our study believed 'too high' pricing served as a disincentive to electric vehicle ownership, and reflected badly on the station owner and/or network operator.

Conversely, pricing that approaches 'free' is considered 'too low.' Drivers believed 'cheap' charging increased the likelihood of a charging station being busy and unavailable to them. They also believed that low prices served as a disincentive for CPOs (Charge Point Operators) to install more charging stations, as sustainable revenue could not be generated by them.

There is, therefore, a 'goldilocks zone' of 'just right' pricing in the minds of drivers. Considering current market conditions, this 'zone' is still fairly broad in absolute dollar terms.

Too high

- "price gouging"
- disincentivises EV ownership
- reflects poorly on CPO / site host

'Goldilocks' zone

- "reasonable"
- less likely to require queueing
- more likely to result in repeat visits

Too low

- more likely to be unavailable and/or require queueing
- no incentive to install more stations

Key recommendations

Carefully design time-of-use pricing strategies to maximise their effectiveness.

Keep it simple: set per-kWh pricing only, and limit the number of pricing tiers (4 or less).

Drivers have developed strategies to translate per-kWh pricing to 'range' and use these strategies to estimate the cost of a charge. Per-minute pricing is considered difficult to estimate, as the duration of a charge is dependent on factors outside of a driver's control. Drivers will choose 'price-certainty' over 'cost-saving', meaning that complex, hard to understand pricing strategies lose out over simpler ones.

Pricing strategies should fall within a driver's model of 'reasonable': no higher or lower.

Drivers create a mental model of 'reasonable' pricing based on the per-kWh price of electricity they pay at home, plus an infrastructure levy, plus a levy for convenience and/or speed.

Pricing plans which are deemed 'too high' are seen as unfair "price gouging", while pricing which is deemed "too low" reduces the likelihood of connector availability and is perceived as a disincentive for charge point operators to install more charging stations.

Key recommendations

Carefully design time-of-use pricing strategies to maximise their effectiveness.

Ensure there are enough connectors available, and implement connector types that are in demand.

At Port Adelaide Plaza, we reached a limit on the number of charge sessions that were possible during 'solar sponge' periods. The charging station was equipped with one CCS2 connector (which the majority of drivers used) and one CHAdeMO charging station (which was rarely used). To increase consumption at grid-favourable times, two CCS2 connectors would have had greater impact.

Charge a premium for speed, but never limit the capacity of a 'fast' charging station.

Considering the scarcity of 'fast' charging stations in general, drivers were against limiting the charging speed of 'fast' charging station during periods of peak energy demand. The concept of speed-limiting was perceived as a "waste of infrastructure, effort and investment" by some. Drivers considered it reasonable to charge a small convenience premium for a faster charge.

Key recommendations

Apply time-of-use pricing strategies only where they create the most benefit – to both drivers and the grid.

Apply time-based pricing to DC fast charging stations frequented by "I want to charge" drivers.

"Want to charge" drivers are topping up and have the flexibility of choice. They are developing habits in this context which are within their ability to change. In contrast, drivers charging at rural superchargers have a limited capacity to change their behaviour: they simply 'need to charge' when they arrive and are less likely to consider the price of charging in their decision-making processes.

Limit time-of-use pricing strategies to locations where the highest potential impact to consumption exists.

There is a cognitive cost to increasing the complexity of a pricing strategy. 'Want to charge' drivers have the option of avoiding charging stations whose costs are difficult to understand and estimate – some may even decide to charge at home instead. Ensure time-of-use pricing strategies are only applied in locations where they will deliver the most benefit to the grid and have the least impact on a driver's charging experience.

Introduction & background

Objective

In 2021, Chargefox initiated a process to install and manage a DC fast charging station at Port Adelaide Plaza. In concert with the South Australian Department of Energy and Mining, our objective was to use this station to trial time-based pricing strategies to explore the effects of pricing on charging behaviour.

EV Smart Charging Trials

The South Australian government has invested $3.2 million in Electric Vehicle (EV) Smart Charging Trials with projects addressing integration risks, service gaps and ways in which electric vehicles can be coordinated to charge.

The trials aim to ensure that electric vehicle Smart Chargers are compatible with current vehicle models, provide the best charging conditions during periods of high renewable energy generation or low grid demand, simplify billing, offer customer convenience, provide route flexibility, and address road trip anxiety.

The trials complement South Australia's electric vehicle statewide charging network, being managed by the RAA and Chargefox with over 500 charging stations at 140 sites in over 50 locations across the state.

With nearly 270,000 electric vehicles forecast to be on South Australian roads by 2030[1] and 1 million electric vehicles integrated into the electricity system over the next 20 years, smart charging options are an imperative factor in electric vehicles becoming a common choice for new car purchase in South Australia.

The trials comprise a number of different focus areas. In this exploratory study, Chargefox focused on the following priority area:

- **Public rapid charging with time-of-use pricing**

Chargefox installed a new metropolitan DC fast charging site to explore how, or whether, drivers responded to changes in charging price, using the Chargefox app and charge management platform as key enablers.

1 AEMO 2022 Integrated System Plan: Updated inputs, assoumptions and scenarios. Accessible at https://aemo.com.au/energy-systems/major-publications/integrated-system-plan-isp/2022-integrated-system-plan-isp/2022-isp-inputs-assumptions-and-scenarios

Over a twelve month period we explored various time-of-use pricing strategies and measured how drivers responded. Time-of-use periods and pricing strategies were developed through an analysis of the spot-price of electricity in South Australia over an 18-month period.

Data from this trial will inform the future direction of electric vehicle policy in South Australia as the SA government aims to make electric vehicles the common choice for motorists by 2030 and the default choice by 2035, in line with achieving net zero emissions by 2050.

About Chargefox

Chargefox is Australia's largest and fastest growing electric vehicle charging network. We're committed to making charging simple, affordable and fast for everyone.

Chargefox was established in 2017 to help meet the need for better electric vehicle charging infrastructure, create innovative technology to support it, and develop software to make it available to everyone.

In 2018 Australian Motoring Services (AMS) a wholly owned subsidiary of the NRMA, RACV, RACQ, RAA, RAC, and RACT, in conjunction with ARENA and the Victorian Government, provided funding for Chargefox to build Australia's largest network of ultra-rapid charging stations, capable of speeds up to 350kW.

In 2023 Chargefox divested from charging hardware to focus exclusively on being the leading software platform for charging and electric vehicle management.

Our expert Australian team now makes it easy for organisations of all sizes to host and manage their own charging stations and transition to an electric fleet.

Chargefox works with companies, governments, and local councils who own charging stations nationwide to bring thousands of publicly available charging options to the rapidly growing number of electric vehicle drivers.

The free Chargefox app is available on the App Store and Google Play, and allows electric vehicle drivers to quickly and easily find a charging station and pay for a charging session.

In future, Chargefox plans to become fully integrated into the infotainment and navigation systems of leading vehicle manufacturers, providing a seamless experience for ever more electric vehicle drivers.

Site selection & station commissioning

Funding guidelines stipulated that grant recipients adhere to the following physical charge station site requirements:

- the site must be located in metropolitan Adelaide
- the site must include at least 2 ports capable of DC charging at a speed of 50 kW or higher
- installed hardware and software must be capable of collecting data on charge sessions, including the start time, end time, rate of charge and total consumption within a session

The project delivered on these requirements in 5 distinct phases:

- Grant submission
- Site selection
- Property owner negotiation and sign-off
- Physical site build
- Commissioning

1. Grant submission

Chargefox's grant submission included the proposed site designs, costs and features required to collect data for the Trial.

Site design, corresponding budget and timeline was based on learnings from site builds undertaken by Chargefox across Australia.

Data collection

Chargefox's charge management platform (Chargefox Administration Portal) includes the ability to gather, visualise and export session data, including session start times, end times, consumption in kWh, current rate of charge and other critical data points relevant to this trial.

Extended data functionality, including the ability to capture idle time (the period in minutes that drivers are plugged into a charging station but not drawing electricity), was introduced over the course of the trial and formed part of agreed in-kind development activity.

At the beginning of the engagement, the Chargefox Administration Portal only provided limited access to charge station datasets. Enhanced functionality was required to extract and analyse detailed charge session data outside of the portal. The cost and effort related to building this additional functionality was also included in agreed in-kind development activity.

2. Site Selection

As of July 2023, Chargefox no longer owns and manages charge station locations and hardware directly. We have, however, built up significant expertise in assessing the feasibility and viability of charge stations based on years of experience[2] of working with diverse stakeholder groups to get charge stations in the ground.

Our site selection process takes the following three factors into consideration:

- existing relationships with stakeholders including planning authorities, local government, property groups and owners;
- the proximity of the site to sufficiently-powered energy infrastructure; and
- a practical assessment of location requirements and constraints, including access, visibility and potential local demand.

Sites are shortlisted on the basis of how they deliver against these factors, with the aim of reducing, as much as possible, the time, effort and cost required to acquire a site licence and secure agreement from all stakeholders on the terms and conditions of the build.

In the case of Port Adelaide Plaza, the location was identified as a potential charging site during investigation work undertaken on other commissioned projects. In addition:

- Port Adelaide Plaza's property owner expressed interest in building an electric vehicle charging station onsite;
- we believed the site had sufficient available power, thus avoiding expensive and time-consuming upgrades requiring approval by the DNSP, and
- an inspection performed by contracted electricians revealed that the site switchboard was capable of handling the additional space and load to facilitate a 120 kW charging station.

A detailed assessment was provided to the Department and the site was approved for use as part of the Smart Charging Trials.

2 See ARENA knowledgebank of Chargefox projects and research https://arena.gov.au/knowledge-bank/?keywords=Chargefox

3. Property owner negotiation & sign-off

This step – even with tacit approval and a signed Expressions of Interest – can be a protracted process, as was the case with the Port Adelaide Plaza site.

The following is an indicative list of issues that required negotiation with the site owner prior to final approval:

- final location of the electric vehicle charging station in the car park
- site considerations, including traffic flow, security and load management
- build cost considerations
- impact of the charging station on adjacent businesses
- additional time to iterate on variation of the Terms and Conditions and final approved contract

4. Site Build

Aside from the often unavoidable delays arising from challenges such as inspections, approvals and equipment availability, the site build itself is a relatively straightforward process.

Delays typically come from issues arising during the early (and less costly) stages of the commissioning process. Once the build is underway, issues are usually manageable, such as safety considerations for the laying of Low Voltage (LV) and High Voltage (HV) cables and their associated regulatory and WHS requirements.

For this project, the laying of an LV cable from the switchboard to the charging station required over 110 metres of cable, which was installed on the roof of Port Adelaide Plaza, then down through the car park to the charging station. Along the roof are egress points which allow access for maintenance workers: in order to comply with WHS standards, cabling needed to be placed on trays that ensured egress points remained safe. This required minor unscheduled works.

In addition, there were scheduling challenges around installing LV cabling underneath the access road to the adjacent Post Office on the site. This was due to Australia Post requiring full access to the road during business hours. Works needed to occur outside of business hours and had to require minimal disruption to traffic flow.

5. Station commissioning

Once a charging station is in place and connected to the energy grid, Chargefox undertakes a commissioning process, which connects the charging station to our platform via the Internet and makes station data available in our Administration Portal. This is achieved using OCPP and OCPI protocols, international standards used to remotely manage charge stations, charging sessions, payments and revenue.

Once Port Adelaide Plaza was connected to the Chargefox Administration Portal, we were able to monitor charge sessions in detail. In addition, pricing and data collection functionality was developed and released as part of approved in-kind activities to support this trial.

> Our recommendation for any entity wishing to install a charging station in a public location is to first invest in detailed upfront design and planning, and second to overestimate the time, effort and cost that may be required to achieve an operational facility.

CCTV camera

A CCTV camera was also installed onsite. This camera had motion and vehicle detection capabilities, allowing us to better understand charge session data: if, for instance, we observed a very short charging session in the data, we could correlate this with time-stamped camera data to better understand the context of the session.

The camera also enabled us to identify instances of ICEing - where charging bays are blocked by petrol vehicles parking in them or using them in some way - and determine the degree of EV queueing in the vicinity of the station. The camera also gave us a window into the behaviours of electric vehicle drivers as they charged and interacted with one another.

Fig 1. Example of camera vision from CCTV
(Chargefox employee pictured)

Research cohort: electric vehicle drivers

Who are Australia's electric vehicle drivers?

Demographic profile

Research suggests[3] that Australian electric vehicle owners are more likely to be male, 35 to 44 years of age or older, have relatively high levels of education, higher annual salaries and more disposable income than the average Australian.

The majority of electric vehicle owners live in detached, single family homes with off-street parking, meaning that most have the option of charging their vehicle at home. The majority of electric vehicle drivers may also have at least one other internal combustion engine (ICE) vehicle at their disposal.

Rogers' Diffusion of Innovation theory[4] describes a bell-curve distribution of consumer sentiment with regards to the adoption of new technology. The Technology Adoption Lifecycle has been widely used across industries to describe the attitudes and behaviours of consumers at different stages of technology uptake.

Research and sales figures suggest that the majority of current electric vehicle drivers in Australia fall into either Rogers' 'innovator' or 'early adopter' category. This is rapidly changing, however, with the 'early majority' beginning to consider the purchase of electric vehicles.

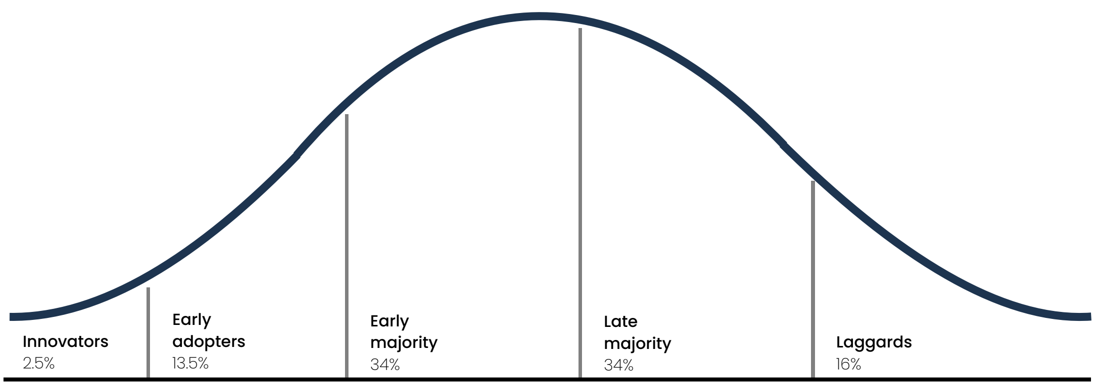


Fig 2. Technology Adoption Curve

3 Patricia Sauri Lavieri, Gabriel Jurado Martins de Oliveira, *Planning for the majorities: are the charging needs and preferences of electric vehicle early adopters similar to those of mainstream consumers?*, Oxford Open Energy, Volume 2, 2024, oiad001, https://doi.org/10.1093/ooenergy/oiad001

4 Rogers, Everett (16 August 2003). Diffusion of Innovations, 5th Edition. Simon and Schuster. ISBN 978-0-7432-5823-4

Early adopters

While 'innovators' and 'early adopters' tend to hold and share strong and vocal opinions about their experiences with new technology, they don't expect innovative products and services to be immediately 'perfect'.

Broadly, 'innovators' and 'early adopters' recognise their status as 'first movers' and have a degree of tolerance for imperfection as products and services mature.[5] Early adopters may even relish the opportunity to participate in the design and development of a new technology on its journey toward maturity.

This is no different in the electric vehicle space. Internal research[6] (including ongoing social monitoring) conducted by Chargefox suggests that current electric vehicle drivers are passionate about electric vehicle ownership, supportive of each other and more than capable of devising and sharing workarounds for challenging or unreliable charging experiences. Broadly, current Australian electric vehicle drivers identify themselves as part of a community of like-minded consumers who are willing to trade the risks and challenges of adopting a new technology for the financial, environmental and 'first mover' benefits of electric vehicle ownership.

Consequently, current electric vehicle drivers are highly engaged. They are visibly active across a number of online communities, posting frequently on message boards, review sites and within community apps. Many will attend events that are geared toward shared community interests.[7] Electric vehicle drivers are vocal about what they believe should be implemented by governments and private companies to improve their driving and charging experience and are quick to share their experiences both online and offline.

In light of the above, we believed that we would require little to no outreach to inform electric vehicles drivers of a new fast charging station at Port Adelaide Plaza, considering existing high levels of driver engagement, the general scarcity of public fast charging stations in Adelaide's metropolitan region and the length of time (18 months) between when the charging station was first publicly announced and when it became operational.

While Chargefox announced the 'opening' of Port Adelaide Plaza's charging station through its own channels, we were careful not to deviate from our standard communications plan: this would ensure that any potential Trial effects observed could be attributed to our pricing changes rather than novel communications strategies.

5 A. Palm, Early adopters and their motives: Differences between earlier and later adopters of residential solar photovoltaics, Renewable and Sustainable Energy Reviews, Volume 133, 2020, 110142, ISSN 1364-0321, https://doi.org/10.1016/j.rser.2020.110142

6 Chargefox maintains an internal repository of customer surveys, interviews, feedback and other analyses. This repository was used extensively to inform our Trial approach

7 See https://thedriven.io/2023/03/13/well-be-back-fully-charged-ruins-15000-weekends-as-ev-demand-nears-tipping-point as an example

The 'Early Majority'

National automotive sales figures are indicating[8] that the 'early majority' consumer may be entering the electric vehicle marketplace, or at the very least considering an EV for their next car purchase.

'Early majority' consumers differ from 'early adopters' in that they are more risk-averse and seek evidence of the clear, concrete and immediate benefits of a new technology. While they are more open and willing to change than the 'majority' consumer, they have a lower tolerance for poor product experiences.[9] As they rely heavily on interpersonal networks for evidence of the benefits of a new technology, poor experiences, shared via word-of-mouth, can be amplified and act as a deterrent.

This suggests that a significant improvement to the availability, reliability and quality of public charging is required to support continued electric vehicle adoption and usage. This is not, however, only an infrastructure challenge - it will also require a change in consumer mindset and behaviour.

Consider the difference between 'filling up' and 'charging' as an example. The task of 'filling up' with petrol diverges significantly from charging or 'filling up' with electrons in a number of ways, requiring drivers to develop a new mental model, and to adopt new habits as a result:

8 See https://data.aaa.asn.au/ev-index/ for up-to-date sales figures

9 A. Palm, Early adopters and their motives: Differences between earlier and later adopters of residential solar photovoltaics, Renewable and Sustainable Energy Reviews, Volume 133, 2020, 110142, ISSN 1364-0321, https://doi.org/10.1016/j.rser.2020.110142

ICE vehicles	Electric vehicles	Change required
Having a 'full tank' of petrol	Charging to 100% reduces the health and life of the battery on some models, while 80% is considered beneficial	Drivers need to 'charge to sufficiency' rather than 'fill up' completely, depending on the model of their vehicle
Filling up' consistently takes 2 - 3 minutes, and doesn't vary station to station	Charging times currently vary from 15 minutes to 12+ hours depending on the vehicle and charging capacity of each 'plug'	Drivers need to make time for charging, and consider what to do with their time while charging
Petrol stations are easily and conveniently located almost anywhere	Limited public charging infrastructure, but a potential 'station' in every home	Drivers may need to pre-plan their trips based on their available and required range
Standard nozzle design (petrol or diesel) that works for all vehicle makes, models and years of manufacture	4 different plugs currently in use, some which are proprietary to certain makes, models and years of manufacture. Some charging stations require drivers to bring their own cable, as well.	Drivers need to identify the stations that support their plug type
A standardised bowser design ensures the same familiar 'steps' are required at every station, with small variations	Charging sequence or 'steps' differ depending on hardware design and station setup	Drivers need to learn new charging processes, usually on the spot
Pricing that is 'fixed' throughout the day and/or week and is sensitive to competition within a narrow range	No pricing consistency station to station, with some prices varying throughout the day, and many 'free' charging options available	Drivers need to familiarise themselves with a range of possible pricing options to correctly estimate what it might cost them to charge
Petrol is sold at a single, consistent unit of value: cents per litre	Electricity can be charged at a per-kWh rate, a per-minute rate or vary depending on the speed of the charging station or plug type	Drivers need to familiarise themselves with multiple units of value and learn to estimate cost based on each
Parking' at a bowser is socially unacceptable	Parking' and 'charging' are interchangeable at some stations, while 'parking' is socially unacceptable at others	Drivers need to understand whether norms and etiquette exist when it comes to charging and parking
Fixed emissions impact per litre of petrol	Emissions impact depends on the use of renewable energy, which varies station to station and depends on the time of day	Drivers keen to minimise their carbon footprint need to determine whether a station is 'green' or not

Table 1. Comparison of ICE vs EV features, and what change is required of drivers

To encourage the 'early majority' to take on these and other required changes in mindset and behaviour, clear, concrete and immediate benefits must exist that make electric vehicle ownership appear worthwhile and desirable.

One of the many benefits of owning an electric vehicle is that drivers can pair them with home solar and battery systems, reducing the cost of charging or 'filling up' significantly.

South Australia's success at converting its electricity grid to 100% renewable energy means that this benefit can be amplified: if an electric vehicle driver needs to charge in public when energy is abundant and cheap, e.g. during 'solar sponge' periods in the middle of the day or after a significant wind event, charging technology makes it possible to (almost immediately) reduce the price of charging as a result. This has significant advantages over the price of petrol, which is fixed for long periods of time and sensitive to global and geopolitical factors.

It is hoped that learnings derived from this trial will contribute to the development of driver-friendly pricing approaches which deliver clear, concrete and immediate benefits to the emerging 'early majority' electric vehicle driver, which will further strengthen, support and encourage electric vehicle uptake.

Research objectives & approach

Research objective

South Australia is at the vanguard of the global energy transition, having transformed its energy system from 1% to over 70% renewable energy in just over 20 years. By 2025/2026, the Australian Energy Market Operator forecasts this could rise to approximately 85%. South Australia's aspiration is to achieve 100% net renewables by 2030. In 2021, South Australia met 100% of its operational demand from renewable resources on 180 days over the course of the year (49%).[10]

As a result of this successful transition, South Australia often generates more energy than there is demand during certain periods of the day, causing the per-kWh price of electricity to dip into negative territory.

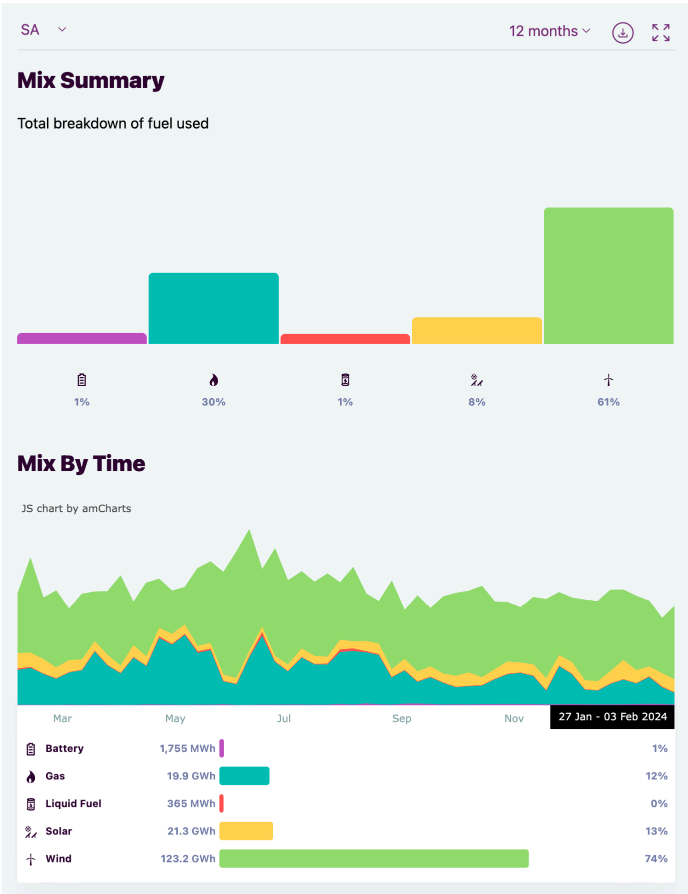


Fig 3. NEM data dashboard showing the contribution of renewables to the South Australian energy grid, accessed at https://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/data-nem/data-dashboard-nem

10 From https://www.energymining.sa.gov.au/industry/modern-energy/leading-the-green-economy#:~:text=South%20Australia%20is%20at%20the,could%20rise%20to%20approximately%2085%25

Periods of peak energy demand coincide with periods of lower renewable generation, however, putting pressure on the stability of the state electricity grid. With the accelerating growth of electric vehicle ownership in Australia, concerns have been raised that the grid will struggle to cope with the increased demand associated with electric vehicle charging, as electric vehicle uptake is currently outpacing growth in renewable energy storage capacity. This is of particular concern during peak demand periods, as some envision that the 'typical' electric vehicle driver will return home from work and plug in their electric vehicle to charge at the most demand-intensive time of the day (e.g. between 5 - 9pm).

> The objective of this research is to explore how electric vehicle drivers might be encouraged to shift their charging behaviour so that the bulk of charging consumption occurs during 'solar sponge' periods in the middle of the day when energy is abundant, using publicly available fast charging stations.

'Fast' and 'Ultrafast' public electric vehicle charging stations concentrate high kWh consumption in a relatively short period of time. The project aims to encourage drivers to charge their battery to sufficiency (80% rate of charge) at a publicly available 'fast' charging station during the 'solar sponge' period and avoid charging during peak demand periods in the morning and evening.

The research and experiments conducted as part of this trial focus on using various aspects of the price of charging to influence charging behaviour.

Over a 12 month research period, we developed a number of pricing interventions that responds to four 'how might we' statements:

- How might we encourage drivers to charge their electric vehicle when wholesale energy is abundant and inexpensive in the middle of the day?
- How might we discourage drivers from charging their electric vehicles during periods of peak energy demand in the morning and evening?
- How might we maximise consumption during 'solar sponge' periods by increasing throughput and reducing median charge session times?
- How might we reduce and/or manage queueing during grid-friendly periods to encourage more public charging overall?

Our initial hypothesis was that, due to the relatively low cost of charging and the affluence of the 'typical' Australian electric vehicle driver, **drivers were not price-sensitive and would therefore not change their charging behaviour in response to a price signal.**

Research approach

Over a twelve month period from December 2022 to December 2023, we captured and analysed charging and consumption data at the Port Adelaide Plaza station. A total of **2349 individual charging sessions** were recorded during this time.

From mid-April to the end of October 2023 we were also able to observe CCTV footage of charging behaviour. We tagged and noted the duration of incidents of ICEing and queueing (where they could be determined).

Over the research period, we ran three experiment cycles of two months each. We implemented distinct pricing strategies in each cycle, informed by the results or hypotheses of the previous cycle, and observed whether the strategy was having any potential effects on:

- the **number of charging sessions**
- **total** and **median consumption** in kWh
- **revenue** generated from electric vehicle charging for the charge point operator
- the **median cost** that electric vehicle drivers paid for a charging session
- the number and median length of **queueing events**

As our research objective was to encourage charging during 'solar sponge' periods, and discourage it during morning and evening demand periods, we needed to first determine the start and end times of each distinct period.

To do this, we collected and analysed the wholesale 5-minute spot price of electricity in South Australia over the 18-month period leading up to the research period.

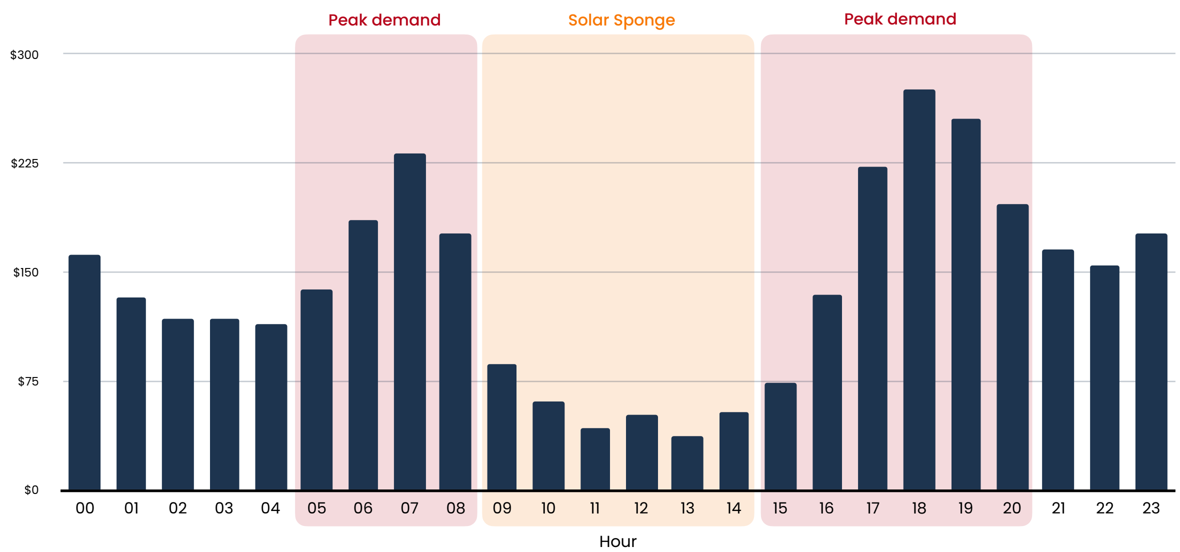


Fig 4. Average wholesale price of energy per hour in SA

Using this data, we determined the average spot price of electricity per hour, and looked for significant increases and decreases in this average hour-to-hour.

This allowed us to determine four time periods for the purposes of defining our pricing strategies:

- **Morning** (5am to 8:59am)
  Peak energy demand, average wholesale energy price per hour of $$
- **Renewable** (9am - 3:59pm)
  Solar sponge period, average wholesale energy price per hour of $$
- **Evening** (4pm - 9:59pm)
  Peak energy demand, average wholesale energy price per hour of $$
- **Night** (10pm - 4:59am)
  Low demand, average wholesale energy price per hour of $$

The pricing strategy developed for each experiment cycle set a distinct per-kWh price for each of the above periods. In experiment cycle three, we trialled a per-minute charge rather than a per-kWh charge.

Idle fees

Chargefox defines an idle fee as a per-minute fee charged to the driver for being plugged in, but not charging. At the time of this study, idle fees were being piloted by Chargefox but had not been implemented widely across the network. We determined that, should 'idle' or 'dwell' time become a limiting factor during our experiment cycles, we would consider implementing it at Port Adelaide Plaza.

In Experiment Cycle Two, Median idle time hovered at 11 minutes during the 'Renewable' period. This is only one minute longer than the grace period (10 minutes) implemented as part of Chargefox's current idle fee feature, and was deemed reasonable for the station, considering the station's location at a shopping plaza.

Consequently, idle fees were not enabled: this limited the number of pricing variables drivers had to contend with, allowing us to establish a stronger causal link between our per-kWh pricing strategies and charging behaviour.

Cycle	Morning	Renewable	Evening	Night	Total
Experiment Cycle Two	13	11	7	13	175
Experiment Cycle Three	12	11	10	12	122

Table 2 Median idle time (mins) at Port Adelaide Plaza station. NB: Functionality to accurately calculate idle time was implemented toward the end of Experiment Cycle Two. Experiment Cycle One is excluded from these figures as a result.

Field observations

Prior to implementing the first pricing strategy, we conducted on-site research to fully understand the context of the charging station location and determine whether local factors existed that may have an influence on behaviour. We used the findings of this activity to design subsequent experiments.

Driver surveys and qualitative research

In addition to analysing raw station data, we wanted to learn more about South Australian electric vehicle drivers. We wanted to understand their attitudes toward the price of charging and their motivations for choosing whether and where they charged in public.

To achieve this, we released a driver survey prior to the first experiment cycle, which helped us determine our first pricing strategy. We followed this with qualitative driver research, in which we interviewed drivers via video conference.

We used the findings of these activities to test hypotheses and design the parameters of future experiment cycles.

In the final experiment cycle, we conducted further qualitative research to challenge and validate the results we were observing.

Driver survey

Objectives

In April 2023, prior to the implementation of our three experiment cycles, we launched a survey of Chargefox users to validate initial hypotheses and refine our first pricing strategy.

A survey was emailed to drivers who had registered for an account in the Chargefox app with a South Australian postcode. We also included any driver who had charged at either Port Adelaide Plaza or Enfield Civic Centre charge stations within the past 12 months (May 2022 - April 2023).

A total of 2728 potential respondents were reached. Survey participants were asked a number of screening questions to ensure that all participants:

- currently owned or had unlimited access to an EV;
- drove their EV regularly, and
- had charged in public within the last 12 months.

Survey respondents

Of the 2728 participants, we received **369** complete, high-quality responses, representing **13.5% of all responses**.

346 respondents (94%) had registered for a Chargefox account with a South Australian postcode, with the remaining 6% of respondents providing postcodes in New South Wales, Victoria, Queensland and Tasmania. **36 respondents (10%)** had charged in Port Adelaide at least once. **Only 16 (4%) respondents** had charged at Port Adelaide Plaza the last time they charged..

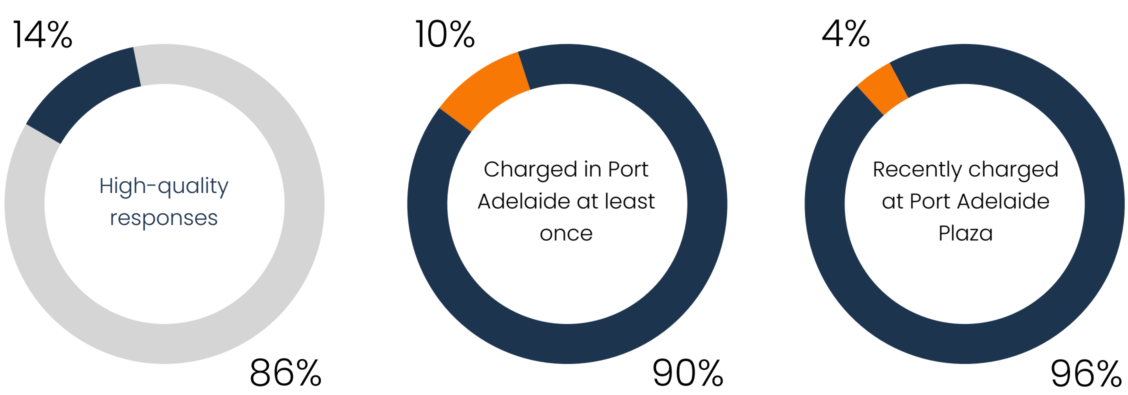


Fig 5. Overview of survey respondents

Findings

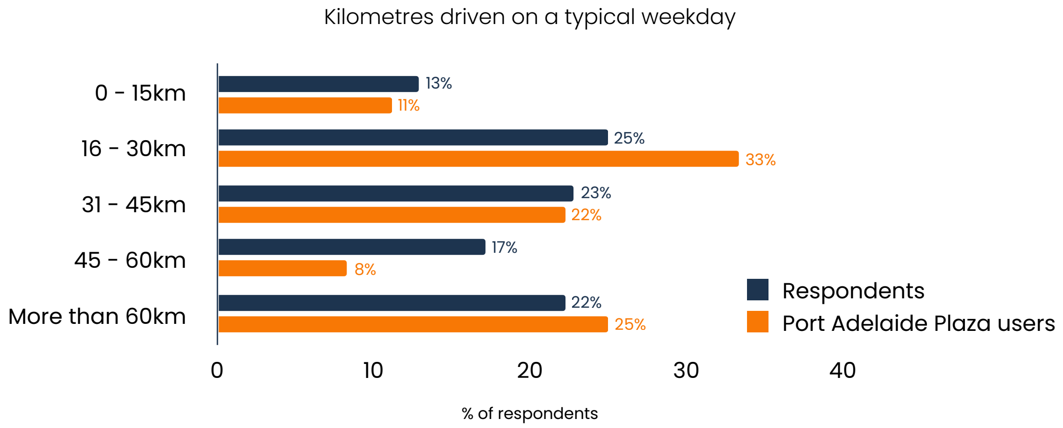
Driving and charging habits

We asked respondents to tell us about their driving and charging habits, and learned that:

- **91%** of respondents were able to charge at home in some capacity;
- **82%** said they drove their EV every day;
- **62%** said they drove more than 30km per day during weekdays;
- **70%** said they drove more than 30km on weekends;
- a higher percentage of respondents who had charged at Port Adelaide (PA respondents) said they typically drove more than 60km on weekends.

Implication

Considering these results, we formed a hypothesis that drivers who charged in Port Adelaide most likely didn't live in Port Adelaide: they were either passing through the suburb or specifically looking for a public fast charging station and willing to travel to use it.



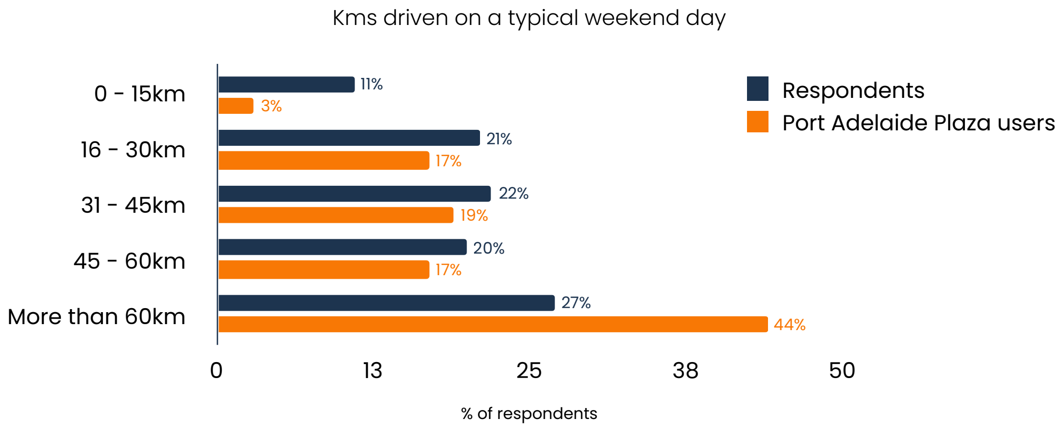


Fig 6. Distance driven by survey respondents

State of charge

To better understand respondents' motivation for choosing to charge at a public charging station, we asked them to estimate, on average, the state of charge of their EV battery when they left home.

We learned that:

- **54%** of respondents reported leaving home with a state of charge above 75%
- **44%** of respondents who had charged in Port Adelaide left home with a state of charge above 75%
- **over 94%** of respondents reported leaving home with more than 50% state of charge

Implication

In absolute terms, considering respondents' state of charge and average distance travelled in a day, we hypothesised that charging at a public charging station may only be a necessity for a driver in limited circumstances.

The implication of this is that any intervention designed to consolidate charging consumption to 'solar sponge' periods during the middle of the day may also need to consider how to motivate drivers to unplug their EVs from their home chargers in favour of charging at a public charge station.

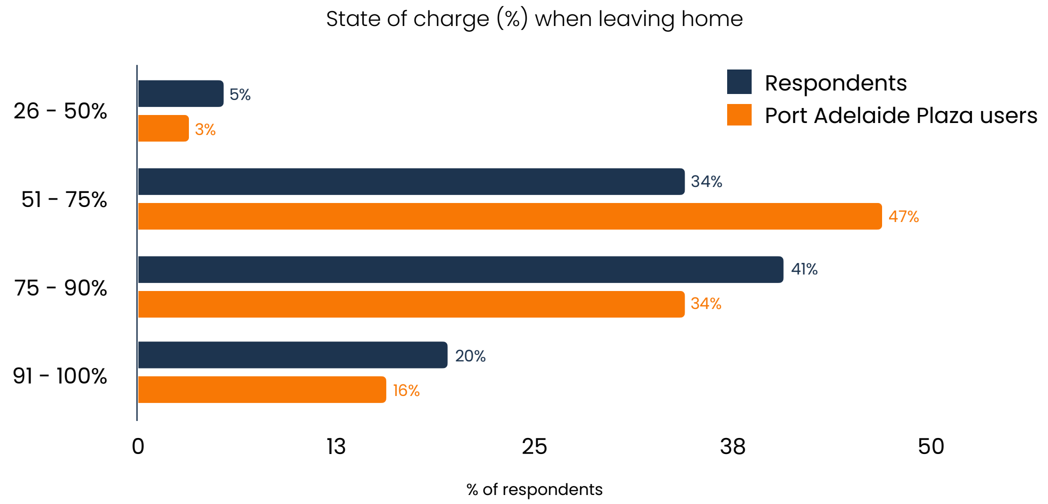


Fig 7. Typical state of charge when drivers leave home

'Renewable' terminology

We wanted to ensure that our pricing strategies were clearly signalling periods of the day in which solar and wind generated the bulk of electricity.

We tested five different terms with respondents, and gave them the option to suggest their own. The five terms were:

- Renewable
- Green
- Clean
- Sustainable
- Climate-friendly

We found that the term 'renewable' is strongly associated with solar and wind generation. 48% of respondents chose this term, with the next most-chosen term being 'sustainable' at 21%.

Implication

This result suggests that using the term 'renewable' to describe periods of the day in which solar and wind energy is abundant will be generally understood and accepted by drivers.

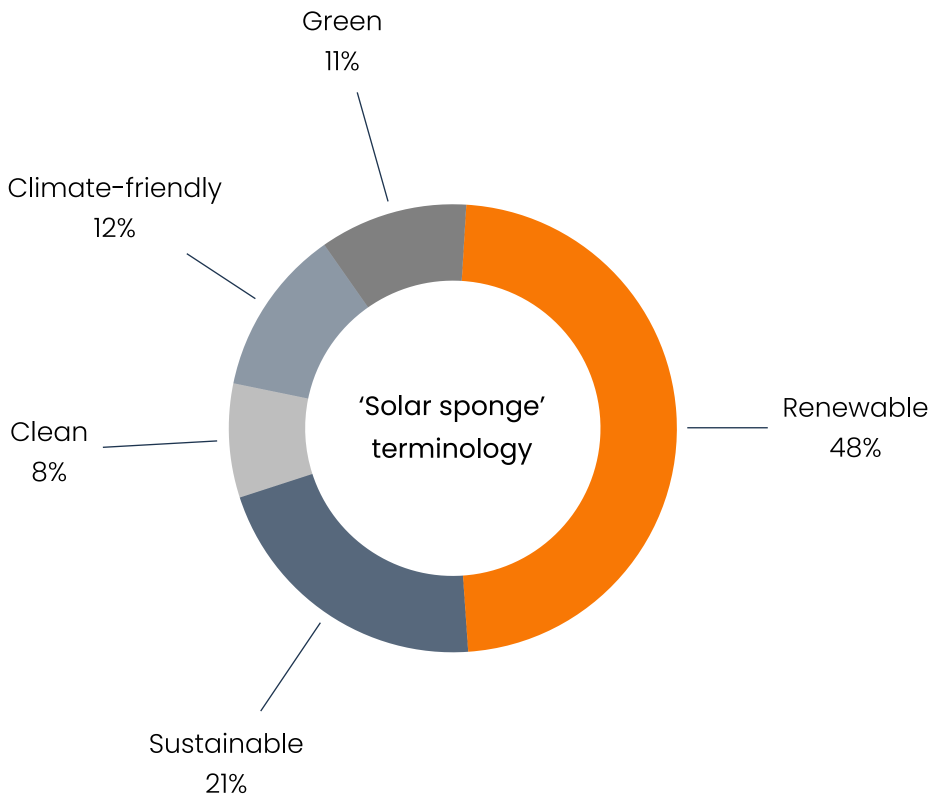


Fig 8. Preferred terms for 'solar sponge' period

Choice of charging station

We asked respondents to tell us what mattered most to them when deciding which public charging station to use. Respondents picked their top three reasons from a defined list of criteria:

- **Availability**
  Is the charging station working? Is it generally busy at this time? Is it currently in use?
- **Reliability**
  How likely is it that the charging station will be operational?
- **Speed**
  How long might it take me to charge, based on the advertised rate of charge at the station?
- **Proximity to other activities**
  What's in the vicinity? Can I do something while I wait?
- **Price**
  How much do I think it will cost me to charge?

We invited respondents to provide other criteria only after they had chosen their 'top three'. Across all respondent segments, the top three things that mattered to respondents were:

- Availability (57% in top three)
- Reliability (51% in top three)
- Speed (48% in top three)

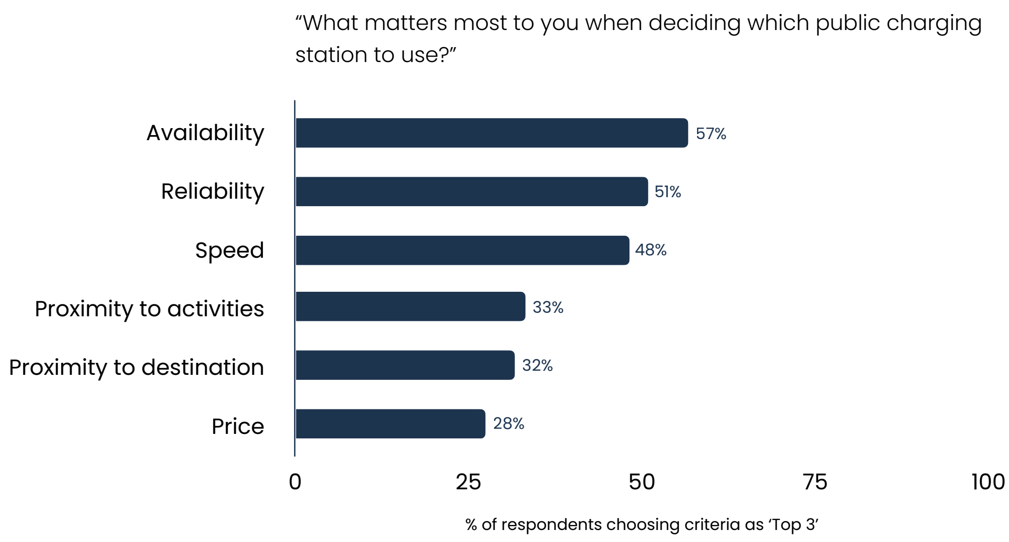


Fig 9. Public charging selection criteria

Choice of recent charging station

We also asked respondents to tell us why they chose the last public charging station they'd charged at. **47%** of respondents told us they they chose their most recent charging station because it was 'the closest to me at the time' (proximity to activities or destination).

Other reasons emerged, however: familiarity with the station came in second, at 21%, and 3% of respondents described the lack of charging options, or 'scarcity' as their reason for charging where they did.

Of the 16 respondents who had last charged at Port Adelaide Plaza, **50%** said they chose the station because of its charging speed rather than for other reasons, which 'Price' being tied for second place (19%).

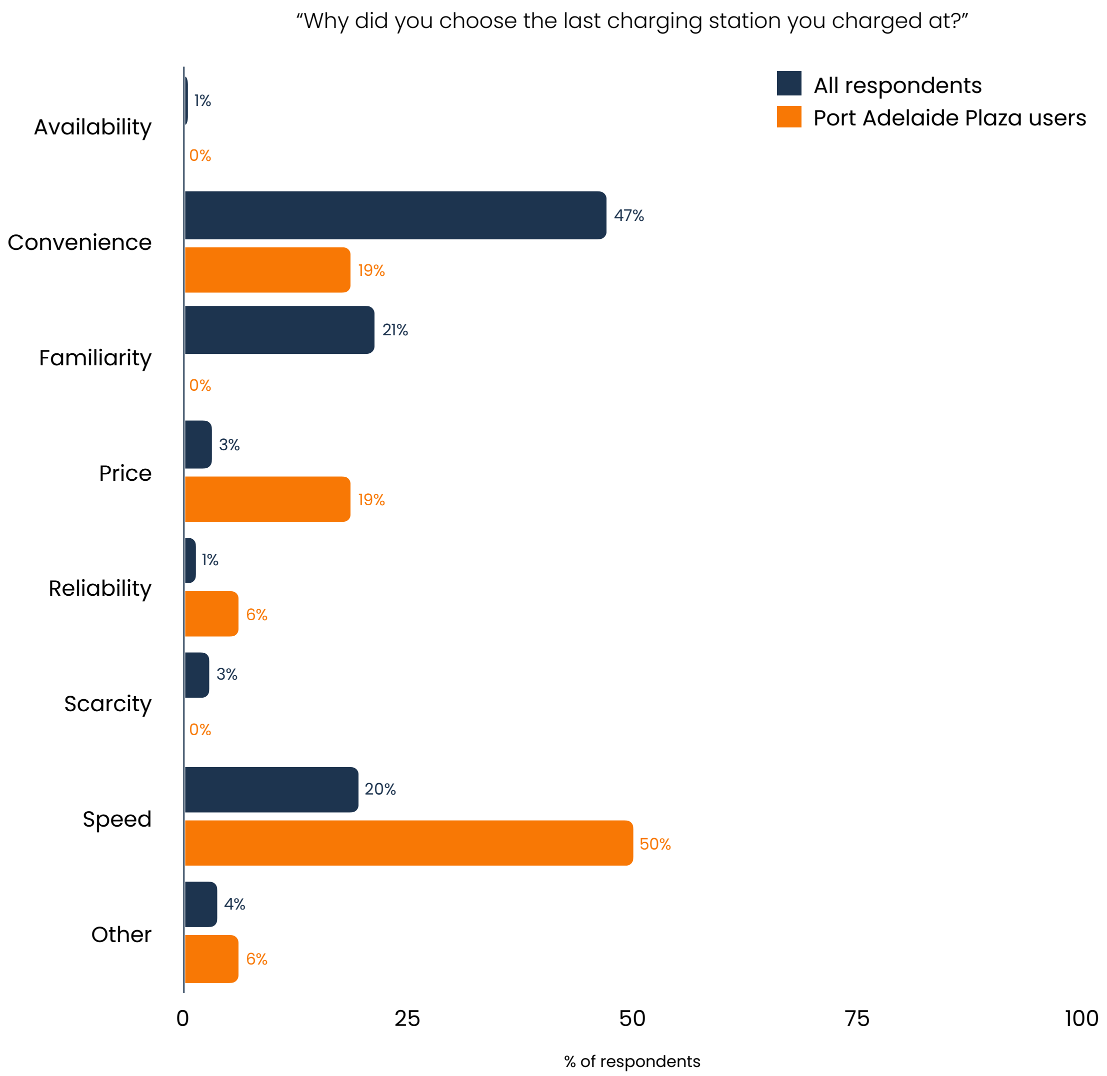


Fig 10. Reasons for choosing last charging station

Implication

These results indicated to us that drivers do not, consciously at least, factor price into their decision-making process when choosing a public charging station. It appeared to validate our initial hypothesis that a price signal would have little to no effect on charging behaviour.

For respondents who had charged in Port Adelaide, however, a picture was emerging as to why people might decide to charge here:

- **Speed**: at 124 kW, the station offers a faster charge than many other public charging options, leading us to a hypothesis that the scarcity of public fast charging stations was driving usage
- **Convenience**: the station was close to attractive amenities, meaning drivers could shop and eat while they charged
- **Availability**: drivers were going out of their way to charge in Port Adelaide, in part because they believed (or observed via the Chargefox app or other apps such as PlugShare) that the station would be less busy due to its location
- **Price**: a cheaper per-kWh charging price might be the ‘cherry on top’ but was not high enough in drivers’ desirability criteria to influence charging behaviour

We believed that the Port Adelaide Plaza charge station was attractive to drivers who valued speed and convenience and who had a lifestyle (time and/or inclination) which enabled them to travel to charge there.

For these drivers, we believed that a price signal would have little to no effect on charging behaviour, as other factors were already attracting them to the station and they would continue to charge at times that were most convenient to them.

The cost of charging

We presented respondents with a number of statements about the price of charging, and asked them whether they agreed or disagreed with them.

Respondents believed that drivers should pay less during periods of peak renewable energy generation, with **79%** either agreeing or strongly agreeing and only 16% ambivalent or 'neutral'.

Responses were less enthusiastic about the concept of paying more during peak energy demand periods, with only **50%** agreeing or strongly agreeing. Notably, a full 28% of respondents were ambivalent. **48%** agreed or strongly agreed to the concept of paying more for charging faster, which registered the highest percentage (30%) of drivers who disagreed.

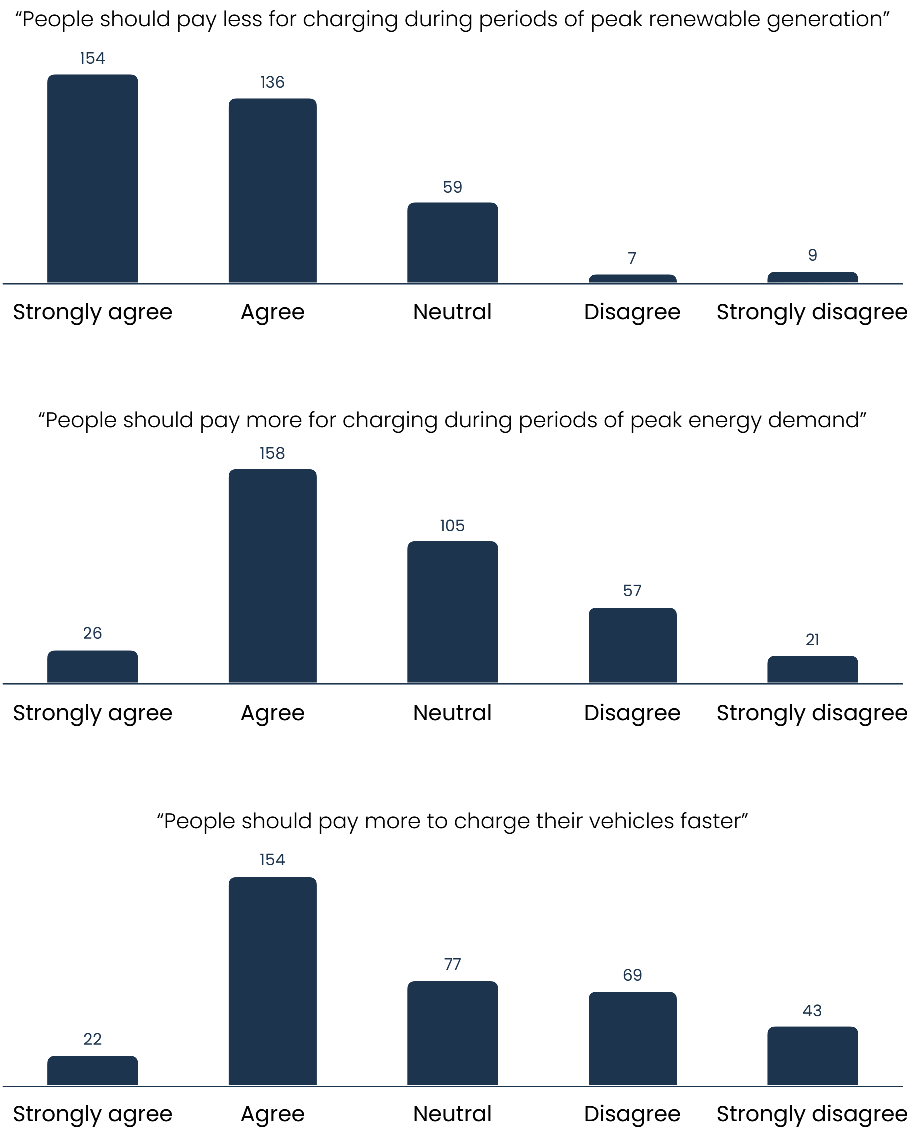


Fig 11. Attitudes toward pricing strategies

Implication

Respondents were broadly supportive and/or accepting of the concept of paying more to charge during periods of peak energy demand, or for faster charging speeds. As our hypothesis was that 'price' did not factor strongly in a driver's decision-making process, we concluded that increasing the price at certain times of the day would not have a overly negative impact on patronage at Port Adelaide Plaza station.

'Need to charge' vs 'Want to charge'

We asked respondents to consider the most recent time they charged their electric vehicle at a public charging station, and to select the reason they charged in public (rather than at home) from a predefined list, with the ability to add their own reasons.

Two segments emerged in response to this question: drivers who '**need to charge**' and drivers who '**want to charge**'.

Need to charge

Drivers who 'need to charge' are **extrinsically** motivated to charge in public: situations or factors outside of their control are compelling them to use a public charging station. We categorised respondents as 'needing' to charge (**49%**) if they articulated one of the following reasons (either from a pre-defined selection or their own description):

- I was too far from home and had a low state of charge
- I was on a long-distance trip and had a low state of charge
- I was preparing for a long-distance trip and had to charge before leaving
- I was unable to charge at home

Want to charge

Drivers who 'want to charge' are **intrinsically** motivated to charge in public: they | have the range and flexibility to choose where, or whether, to charge. We categorised respondents as 'wanting to charge' (**51%**) if they articulated one of the following reasons:

- the charging station gave me the ability to park while I charged
- the charging station was faster than charging at home
- the charging station was cheaper than charging at home
- the charging station gave me the opportunity to 'try out' public charging
- the charging station was near my destination or planned activity

Overall, survey respondents were evenly split, with respondents who had charged at Port Adelaide more likely to be in the 'want to charge' category.

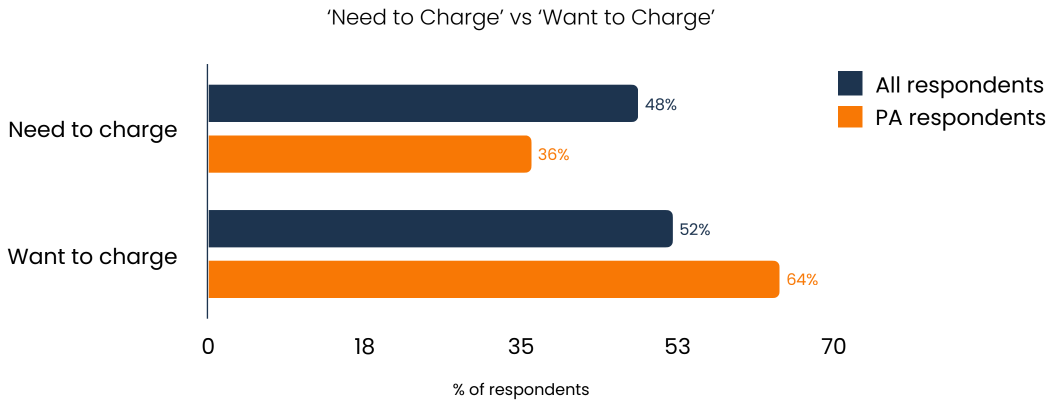


Fig 12. Attitudinal segmentation

Segmenting responses produces results which point to unique set of attitudes, motivations and behaviours when it comes to charging. As an example, more 'want to charge' drivers chose 'speed' and 'familiarity' as the reason they chose their last charging station, and were more strongly in favour of paying less to charge during periods of renewable energy generation.

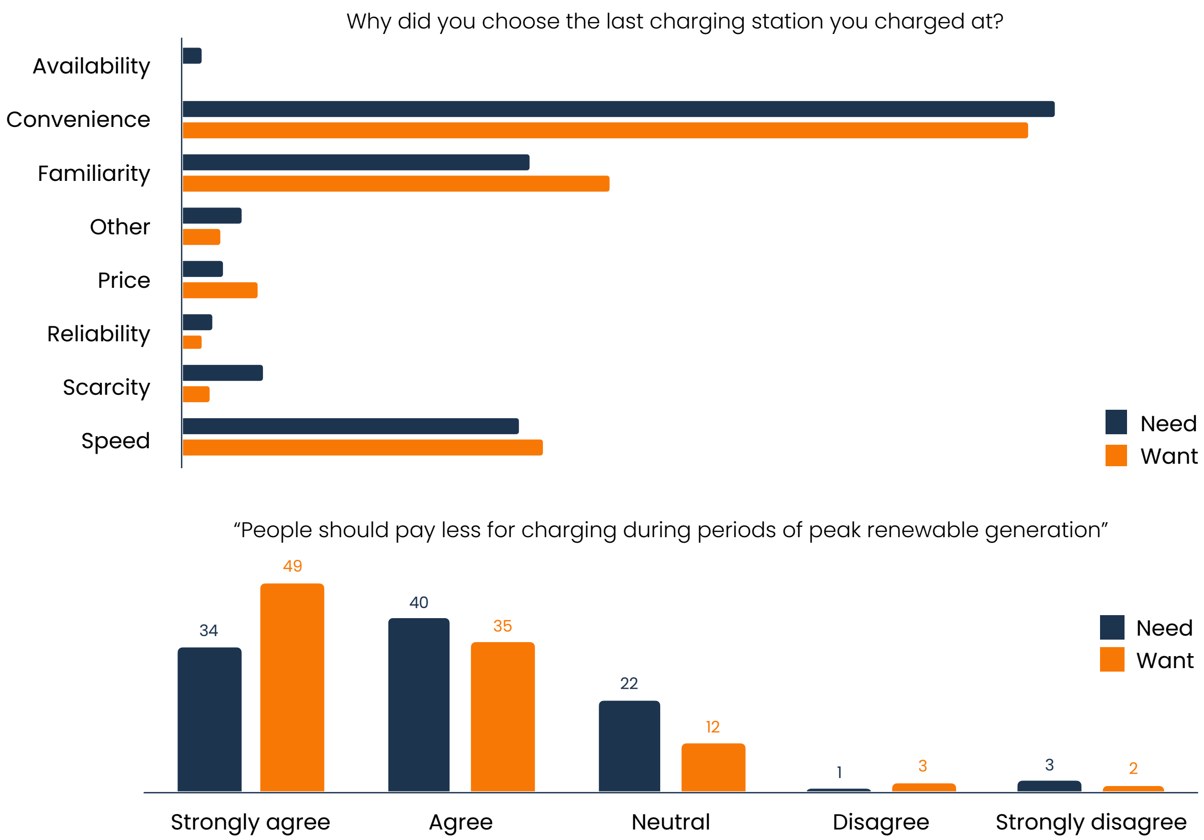


Fig 13. Differences in responses, by segment

Implication

Depending on a driver's current set of circumstances, their decision-making processes and observed behaviour may be different.

Having segmented and re-analysed survey data, we believed that 'need to charge' drivers would be less likely to be influenced by a price signal, as factors such as the risk of losing range and mobility would override any consideration of the price of charging.

We believe that 'want to charge' drivers may be more susceptible to a price signal as they have the ability to 'shop around' to meet their criteria set (availability, speed, convenience, etc.).

Summary

When electric vehicle drivers consider charging their car at a public charging station, they ask themselves **four key questions**:

- How urgently do I need to charge?
- Is the charging station working and available?
- Will I have to wait to use it?
- How long will it take me to charge (and what will I do while I'm waiting)?

Price is of lesser concern, and thus less of an influencing factor on station choice. Should drivers receive satisfactory answers to their four key questions, however, the price of charging may then enter into their decision-making.

This result appeared to reinforce our initial hypothesis that we would not be able to shift charging behaviour with a price signal. At this early stage of our research, we did not account for a number of factors influencing driver motivation, including the scarcity of fast charging stations; the role home energy generation plays in choosing to charge in public; and the compulsion of early adopters to seek to amplify the benefit of their 'risky' technology choice.

In follow up driver interviews, we explored these factors in more detail, and gained a better understanding of what compels drivers, particularly 'want to charge' drivers, to charge in public rather than at home.

Driver interviews

Objective

To coincide with the launch of Experiment Cycle One, we conducted in-depth interviews with 10 drivers selected from our pool of survey respondents.

The purpose of this activity was to better understand factors that influence charging behaviour, particularly those relating to price.

Interview participants

Of the 10 respondents selected for interview:

- 10 were EV owners who had recently charged at a public charge station
- 4 identified as female
- 6 identified as male
- 8 were South Australian residents
- 2 had travelled through Adelaide and rural South Australia on a trip from another state
- 1 had charged at Port Adelaide Plaza recently
- 2 lived in regional areas of South Australia, where public charging was scarce

Approach

We invited participants to a 1:1 online interview via Google Meet, in which we asked questions about the participant's experience of purchasing and driving an EV, how and why they charged at home and in public, and what their expectations were around the cost of charging. We also presented them with a number of pricing constructs, visualised as screens in the Chargefox app, and asked for their feedback and preference.

Findings

What is a 'reasonable' price?

We asked participants to articulate what they felt was a 'fair' or 'reasonable' price for charging their EV at a public charge station, and what situations or contexts might affect their perception of 'reasonable.' We did this to understand how drivers evaluate the advertised price of charging at a charging station, and to help us better define the upper and lower limits of the pricing strategies we would apply to Port Adelaide Plaza.

When determining whether a public charge is 'reasonably' priced, drivers take four factors into consideration, in order of importance:

1. **My remaining range**
   Can I make it to a cheaper charging option with the range I have?

2. **The cost of charging at home**
   How does this price compare to my home energy rate?

3. **The time I have available**
   Will I get a sufficient charge in the time I have available?

4. **Other amenities available**
   Are there things I can do in close proximity while my car is charging?

The last two factors broadly align with findings from our driver survey, while the first two factors point to the mental modelling that drivers undertake when they try to estimate the cost of a charging session.

The 'price of charging' mental model

We delved further into this modelling process with participants so that we could better define and understand it.

Drivers expect to see a per-kWh charging rate that is commensurate with their home energy rate, plus a reasonable margin that covers the cost of infrastructure, plus a 'convenience premium' that applies to 'fast' charging stations (roughly, 'fast' means a charging station capable of fully charging an EV in under an hour[11]).

11 'fast' is broadly defined as a charging station capable of fully charging a vehicle in less than an hour, as per the Electric Vehicle Council of Australia's definition of a 'Level 3 / Mode 4' charging station: https://electricvehiclecouncil.com.au/a-z-charging/

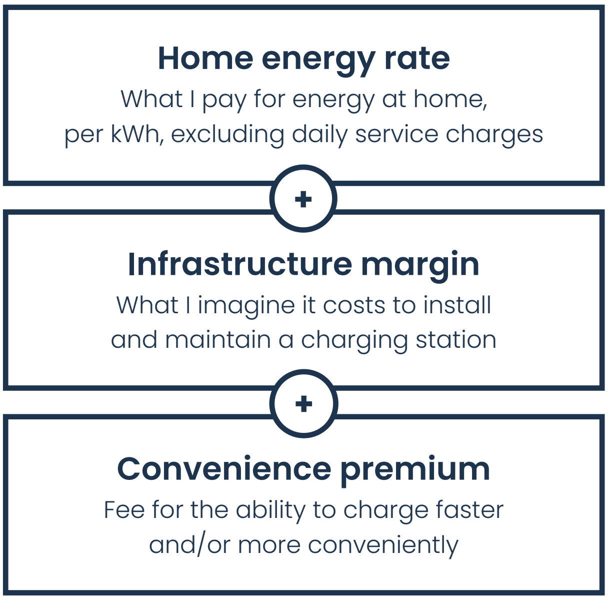


Fig 14. 'Price of charging' mental model

The 'goldilocks zone' of price

Participants were not concerned about the cost of charging going up, so long as it did not approach parity with the per-litre price of petrol.

This aligns with research previously cited that places the majority of current Australian electric vehicle drivers as 'innovators' and 'early adopters' who have sufficient income to absorb or adapt to rising costs: EV drivers are less price-sensitive in an absolute sense, but keen to protect their advantages and benefits as 'first movers' in the EV space.

Internal research conducted by Chargefox shows that electric vehicle drivers support price increases and/or fines if they result in an experiential benefit: as an example, electric vehicle advocacy groups have been agitating for the roll out of punitive idle fees across the charging network to help normalise 'fair' and 'acceptable' charging behaviour[12].

Uniquely, this means that EV drivers may welcome price increases in certain circumstances. The drivers we interviewed believed pricing that was 'too low' discouraged the installation of public charging stations, as site hosts would not be able to generate sufficient revenue to support them – resulting in fewer stations being built (a negative outcome). Stations with very low prices were considered more likely to be busy and unavailable, increasing the prospect of having to queue.

At the other end of the spectrum, pricing that was 'too high', e.g. near parity with the per-litre price of petrol, was considered 'price gouging,' particularly as there are situations in which EV drivers are not able to choose the time or location of their charge due to low state of charge and the lack of public charging infrastructure ('need to charge').

12 See https://thedriven.io/2023/06/14/chargefox-to-introduce-idle-fees-to-encourage-better-use-of-ev-charging-stations/ as an example

Too high

- "price gouging"
- disincentivises EV ownership
- reflects poorly on CPO / site host

'Goldilocks' zone

- "reasonable"
- less likely to require queueing
- more likely to result in repeat visits

Too low

- more likely to be unavailable and/or require queueing
- no incentive to install more stations

Fig 15. 'Goldilocks zone' of expected price

Considering that 51% of the electric drivers that we surveyed charge at a public charging station because they 'want' to, rather than having a 'need' to, a charging station that sets the cost of charging too high risks alienating customers who have the choice of choosing a different station, or simply not charging in public at all. Conversely, because of the perceived scarcity of public charging stations, a 'free' or 'cheap' charging station increases the likelihood of queueing, which is unfavourable to drivers with the ability to plan their charge ahead of time (or charge at home instead)

Implication

The findings of the driver survey were delivered halfway through our first experiment cycle, in which our pricing strategy was set at 'extreme' ends of the pricing spectrum.

We used our new understanding of a driver's 'price of charging' mental model and 'goldilocks zone' to set pricing for the next experiment cycle: we both increased 'low' pricing during solar sponge periods and decreased 'high' pricing during periods of peak energy demand, with the hypothesis that this would have a minimal to weakly positive impact on charging behaviour, and a positive impact on the revenue generated for charging station owners and operators..

Price construct testing

In the Chargefox app, users can see and select charge stations from a map by tapping on the station's 'pin.' This reveals an at-a-glance summary of station information, including a price range for charging. Users then tap a 'Details' button to see a detailed pricing breakdown and can start a charge. This second screen is called the 'Location Details' screen.

We showed participants four variations of the 'Location Details' screen, each representing a different pricing construct. Considering that survey respondents told us they were willing to pay more for 'fast' charging, we wanted to test concepts that priced the rate or speed of charging as well as the time of charging.

A. Time-based

Pricing construct that was currently applied at Port Adelaide Plaza at the time: four time periods corresponding with 'solar sponge' and peak energy demand, priced accordingly:

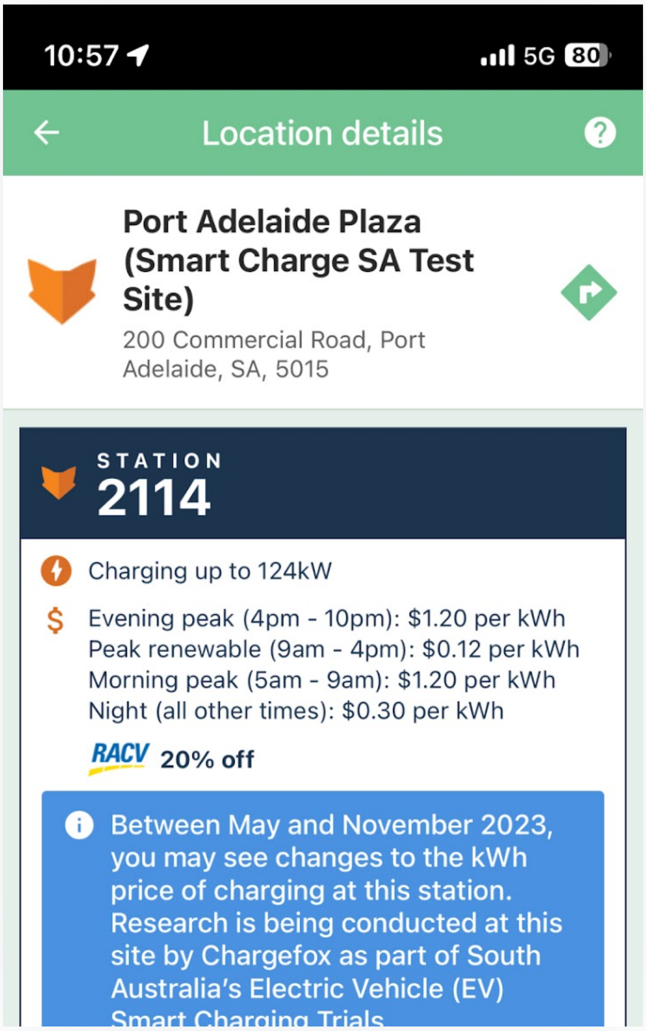


Fig 16. Port Adelaide Plaza's 'Location details' page in the Chargefox app

B. Speed-limited

Pricing consistent with the previous time-based construct, but with the addition of a 'speed limit' on the rate of charge during periods of peak energy demand:

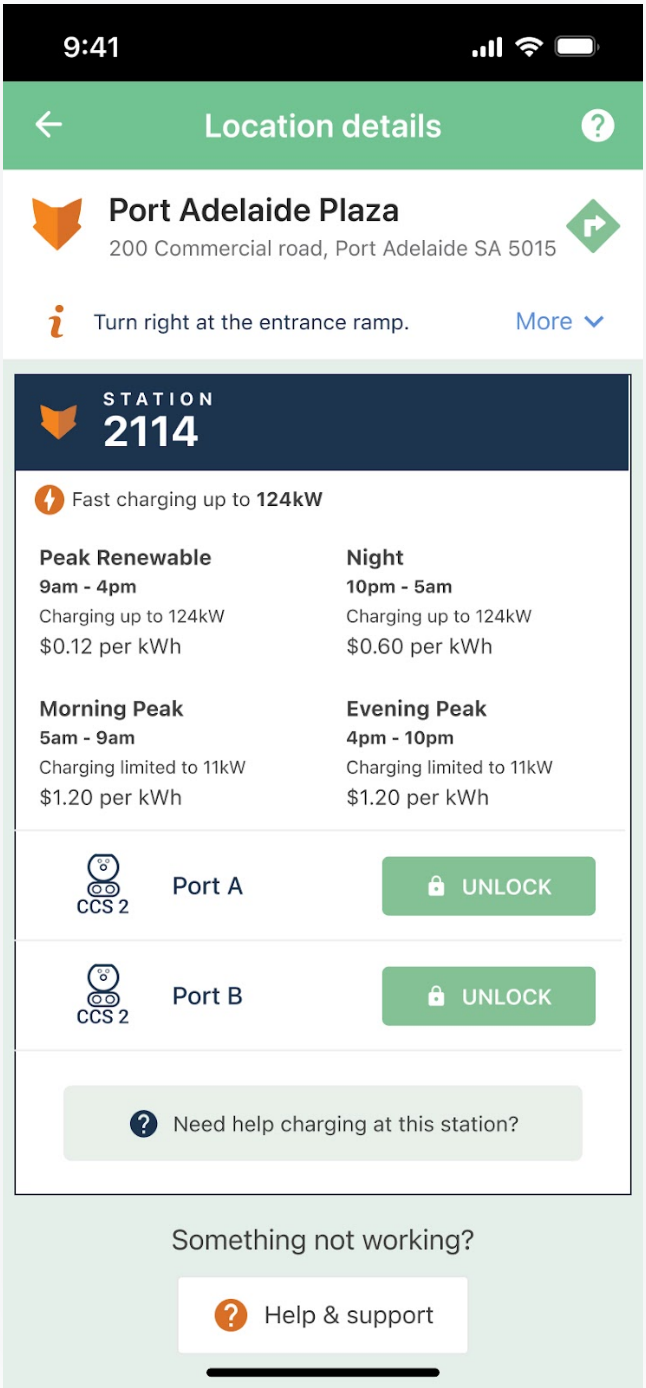


Fig 17. 'Speed limited' concept

C. Boost

Speed-limited construct, as above, but drivers have the ability to 'boost' their charging speed to the maximum available rate of charge by paying an additional fee at the click of a button:

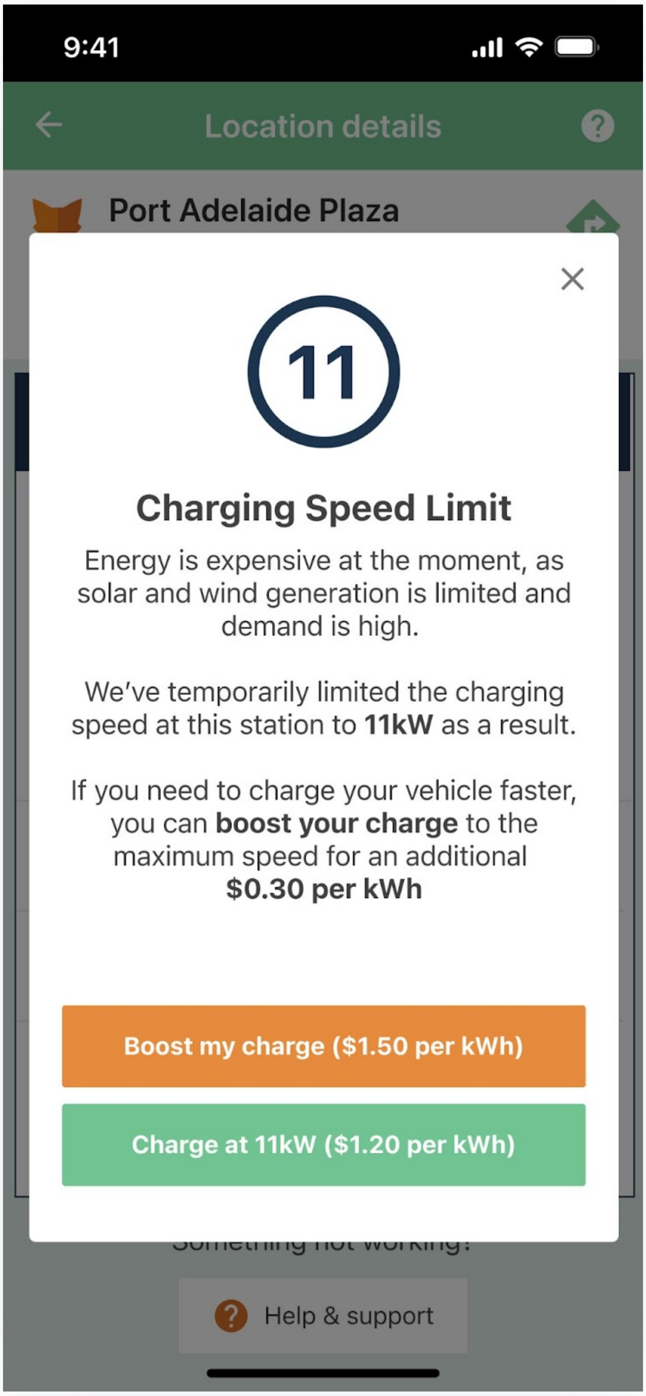


Fig 18. 'Boost' concept

D. Choose your speed

A variation on the above. Instead of default 'slow' charging with the ability to 'boost', all drivers are given the option to choose to charge at low, medium or high speeds, with corresponding pricing:

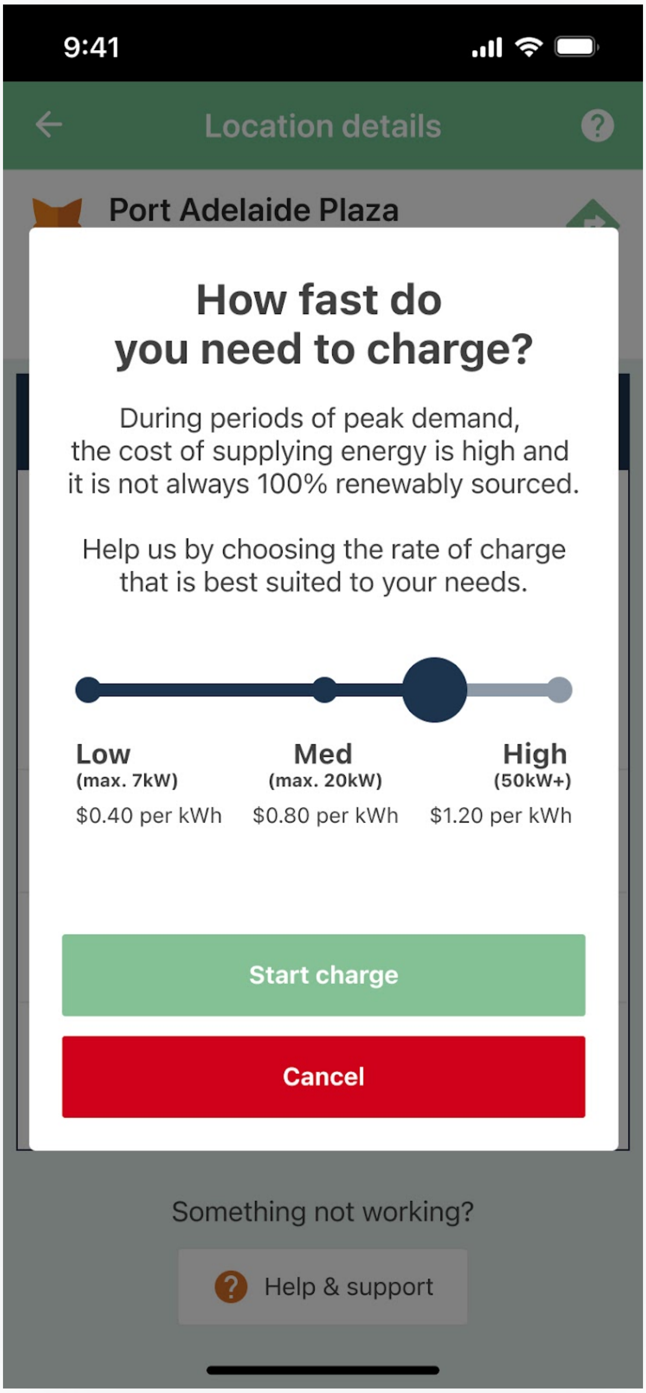


Fig 19. 'Choose your speed' concept

Results

Participants were very passionate, and vocal, in their feedback about which of these four constructs they favoured.

Drivers seek out charging stations that are significantly faster than home charging due to their convenience and relative cost-effectiveness. We learned from participants that attempting to limit the speed of a fast charging station renders it 'useless' to drivers on both counts. The significant time and effort required to install a fast charging station, and the resulting scarcity of public fast charging stations, means that limiting the speed of a fast charging station renders the infrastructure investment pointless or a ‘waste of time and money’. From this perspective, participants rated both constructs B and C very poorly.

While construct D raised participants’ interest, the speed-limiting factor remained a detractor. Participants described what might occur if, during periods of high charging demand and queueing, a driver decided to charge at a ‘low’ rate of charge and occupy a port for a number of hours. In one participant’s words, ‘This would start a war.’ Again, this is due to the scarcity of public fast charging stations, which appears to be well-known.

Implication

While fast public charging stations remain scarce, any investment in fast charging needs to deliver fast charging without exception, otherwise it risks being seen as a waste of money and resources.

> We recommend avoiding pricing strategies that artificially curtail the maximum rate of charge unless and until public fast charging stations are abundant and ubiquitous.

As a result of this research, we opted to apply a pricing strategy in experiment cycle two which was a variation of experiment cycle one, roughly in line with the pricing construct (A) favoured by participants.

Another key takeaway was a better understanding of how the scarcity of fast charging stations factored into a driver’s decision-making process. ‘Want to charge’ drivers may be compelled to charge quickly and cheaply at a convenient location, even if it meant driving further to do so: this may go some way to explain the results we were seeing in Experiment Cycle One.

Experiment cycles

Across three, two-month experiment cycles, we trialled different pricing strategies to determine whether we could influence the time and duration of charging sessions, understand which pricing strategies were most effective and develop a theory as to why.

Specifically, we sought to:

- encourage drivers to charge their EVs when energy is cheap and abundant in the middle of the day
- discourage drivers from charging their EVs during periods of peak energy demand
- maximise consumption at grid-friendly times by increasing throughput and reducing median charge session times
- reduce and/or manage queueing during grid-friendly periods to encourage more public charging

Baseline conditions

The Port Adelaide Plaza charging station became available to the public on December 14, 2022.

An initial pricing strategy was applied to the station, as follows:

- $0.10 per kWh from 12am to 6am
- $0.50 per kWh from 6am - 2pm
- $1.00 per kWh from 2pm to 8pm

This pricing was based on a rough assessment of similar time-of-day pricing strategies applied to fast charging stations in other locations across the Chargefox network, and a simple 2:1 ratio between high and low price points.

These time periods were not named - they simply appeared as times and prices on the 'Location details' screen of the Chargefox app. The screen also included a message to drivers indicating that a Trial was currently in place, and to expect periodic changes in pricing.

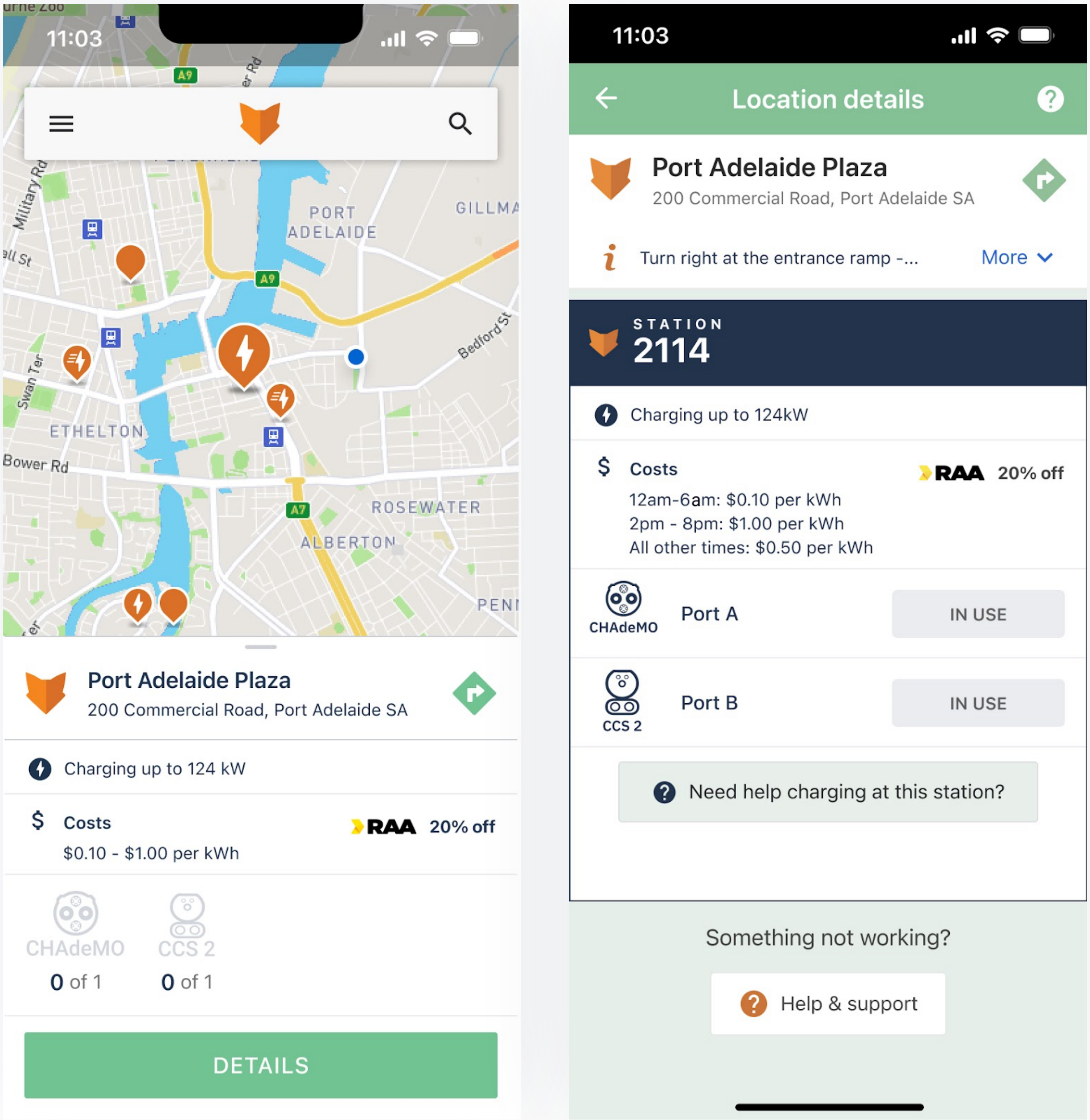


Fig 20. Baseline pricing strategy

For our experiment cycles, we determined four time-periods which aligned with variations in the wholesale 5-minute spot price of electricity in South Australia:

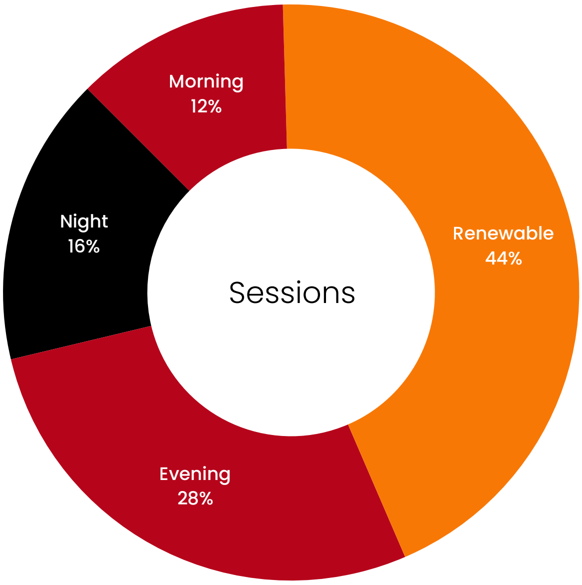
- Morning energy demand: 5am to 9am
- Peak renewable generation: 9am - 4pm
- Evening energy demand: 4pm - 10pm
- Night: 10pm - 5am

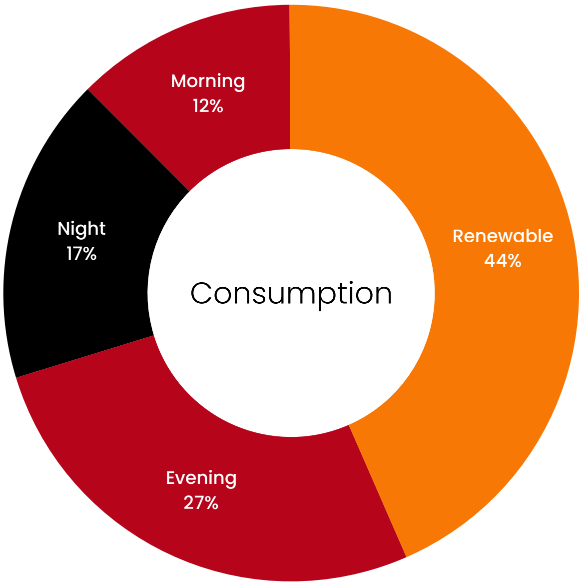
Charge session data captured from the two months (March 1 to April 30, 2023) preceding our first experiment cycle was:

Baseline data
1 Mar – 30 Apr 2023

Sessions	Consumption	Median consumption
191	6347 kWh	33.5 kWh

Measure	Morning	Renewable	Evening	Night
Number of sessions	23	84	53	31
Total consumption	787.46 kWh	2762.77 kWh	1701.75	1094.77 kWh
Median consumption, per session	33.14 kWh	33.92 kWh	32.77 kWh	37.44 kWh
Total session duration	869 mins	3040 mins	1701 mins	1219 mins
Median session duration	38 mins	34 mins	30 mins	44 mins
Total cost to driver	$131.96	$408.57	$382.15	$77.65
Median cost to driver, per session	$5.74	$4.86	$7.21	$2.50





Implication

The Port Adelaide Plaza charging station did not appear to be popular, considering the scarcity of operational public fast charging stations at the time and the exponential growth in EV sales recorded over the period.

Anecdotally, among interview participants Port Adelaide was considered ‘out of the way’ or ‘across town.’ Baseline pricing was clearly not incentivising drivers to make the trip at any time of the day.

Looking at the median cost of charging even at the most expensive period of the day ($7.21 per session during the ‘evening peak’ period), we believed that because EV drivers weren’t price-sensitive in an absolute sense, and the total cost of charging was so low, a price signal would not be capable of influencing charging behaviour.

Considering usage data at Port Adelaide Plaza to date, we expected little to no change to usage in our upcoming Experiment Cycle.

Experiment cycle one

From 1 May to 30 June, a pricing strategy was applied to the station which aligned with our defined time-periods, with a 10:1 ratio between high and low price-points.

Morning	Renewable	Evening	Night
energy demand:	generation:	energy demand:	low demand:
5am - 9am	9am - 4pm	4pm - 10pm	10pm - 5am
$1.20	$0.12	$1.20	$0.30

The strategy was displayed in the Chargefox app as follows:

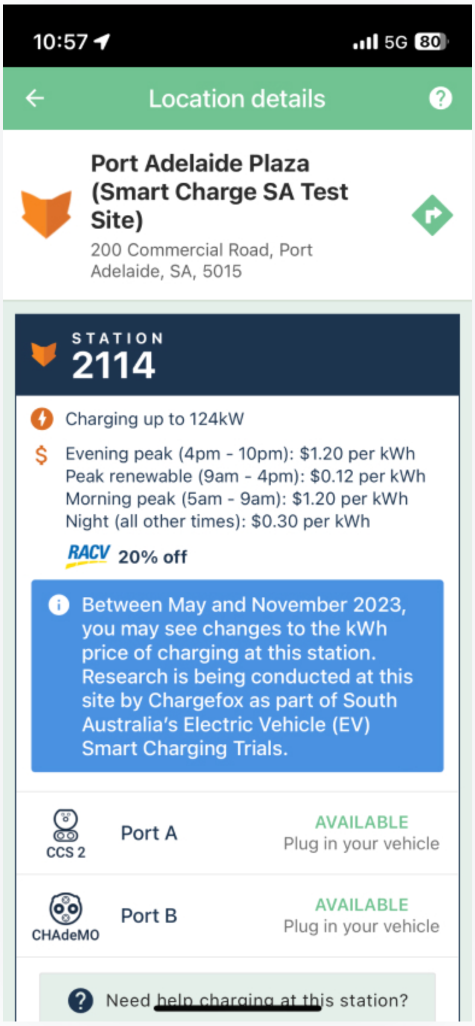


Fig 21. Pricing strategy displayed in experiment cycle one

Charge session data captured for these periods (May 1 to June 30, 2023) was:

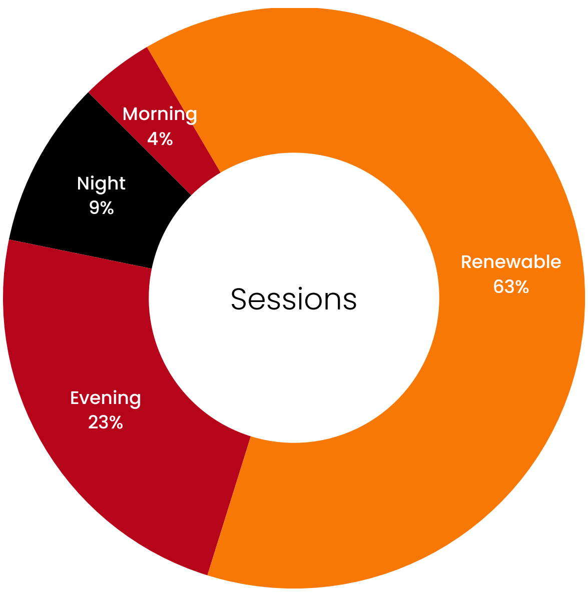
Experiment cycle one results
1 May – 30 Jun 2023

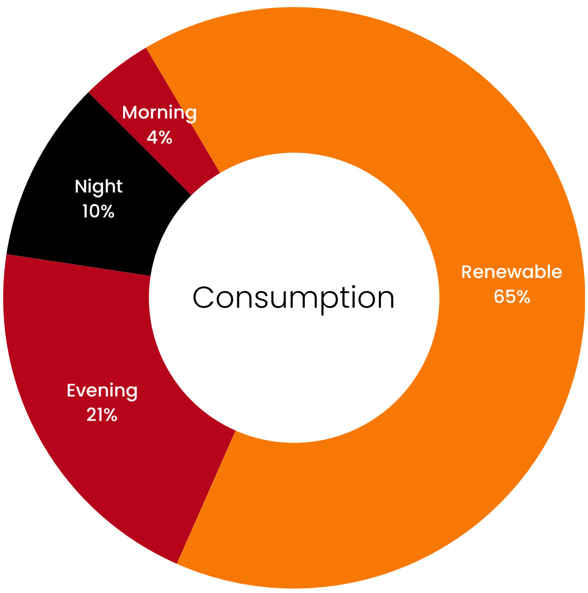
Sessions
517
171% increase

Consumption
16667 kWh
163% increase

Median consumption
32.8 kWh
2% decrease

Measure	Morning	Renewable	Evening	Night
Number of sessions	21	327	121	48
Total consumption	664.89 kWh	10852.42 kWh	3465.61 kWh	1683.84 kWh
Median consumption, per session	29.10 kWh	33.23 kWh	27.75 kWh	37.29 kWh
Total session duration	792 mins	12763 mins	3907 mins	1776 mins
Median session duration	40 mins	40 mins	30 mins	34 mins
Total cost to driver	$378.14	$954.52	$876.88	$385.74
Median cost to driver, per session	$18.01	$2.92	$7.25	$8.04





These results surprised us. To rule out any seasonal variation in the data recorded, we compared consumption and usage at Port Adelaide Plaza with a number of similar stations across Australia.

The results at Port Adelaide Plaza were well above what may be seasonally expected in May - June due to lower rooftop solar generation potential and consequent constraints on home charging for drivers with rooftop solar systems.

Note below: growth in consumption at Port Adelaide Plaza (station 2114, orange) during the 'Renewable' period outpaces growth at comparable stations. Conversely, growth in consumption during periods of peak energy demand trends lower at Port Adelaide Plaza compared to the same stations.

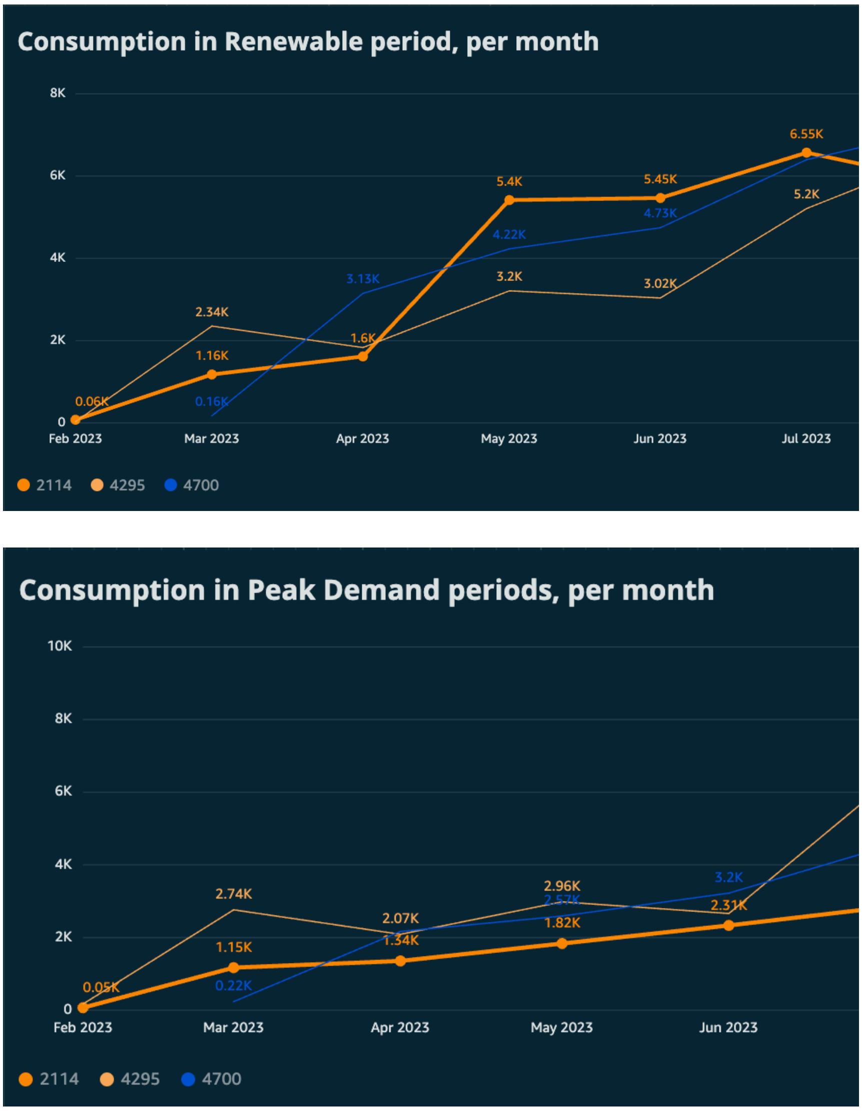


Fig 22. Comparison of Port Adelaide Plaza consumption (2114) with other, similar charge stations on the Chargefox network (4295, 4700). Consumption in peak demand periods trends lower at Port Adelaide Plaza than at other stations, while consumption during 'Renewable' period trends higher.

Implication

When we reduced the per-kWh price of charging during the 'Renewable' period in the middle of the day, we saw a significant increase in the number of charge sessions overall at Port Adelaide Plaza - our pricing strategy 'put the station on the map' without having to employ any additional communications or outreach.

This increase in patronage corresponded to an increase in overall consumption, which was most significant during the 'Renewable' period (293% increase). This corresponded with a decrease in total consumption during the morning peak period (15% decrease).

Based on these results, we believed that our initial hypothesis was incorrect: clearly, our price strategy was influencing when and where electric drivers were choosing to charge their vehicles, with drivers choosing Port Adelaide Plaza over other charging options and shifting their charging to cheaper periods where they could.

We considered other factors that may explain the sudden increase in usage, including seasonality and a surge in EV ownership. None of these appeared to be having an outsized influence on the results of the experiment: more drivers were coming to Port Adelaide Plaza to charge, and they were choosing to charge at times that fell outside of periods of peak energy demand, particularly the evening peak.

Based on findings from qualitative research, we believed this to be the result of 'want to charge' 'early adopter' electric vehicle drivers seeking to maximise the benefit of their investment at a location which satisfied their 'key four' desirability criteria. The general scarcity of fast charging stations in the market at the time may have also been playing a part.

Toward the end of the Experiment Cycle, our pricing strategy received attention from both industry and community press, with one publication dubbing Port Adelaide Plaza as 'the most expensive EV charge station in Australia' before conceding that pricing within renewable periods was far lower than most comparable stations.

Learnings for Experiment Cycle Two

Based on these results, as well as insights from qualitative driver interviews, we opted to continue with time-based pricing, but experiment with decreasing the upper value and increasing the lower value of the pricing strategy's price range.

Experiment cycle two

Objective

With a better understanding of an electric vehicle driver's 'price of charging' mental model (an insight from R1 Driver interviews), we wanted to test the bounds of drivers' perceived 'expected' price range. We slightly raised the per-kWh price of charging during the day, and lowered it during periods of peak energy demand.

Our hypothesis was that, if our pricing strategy remained within the bounds of 'expected' pricing, we could generate a more sustainable revenue stream for site hosts without compromising the grid-friendly charging behaviour we were observing. This would provide more incentive for site owners to commission public charging stations, while curtailing driver perceptions of a station's availability and/or the potential for queueing.

Pricing Strategy

From 1 July to 31 August, a pricing strategy was applied to the station which decreased the price during periods of peak energy demand and increased the price within the 'Renewable' period, with a ratio of 5:1 between high and low price points.

Morning	**Renewable**	**Evening**	**Night**
energy demand:	generation:	energy demand:	low demand:
5am - 9am	9am - 4pm	4pm - 10pm	10pm - 5am
$0.90	$0.18	$0.90	$0.45

Charge session data captured for these periods (July 1 to August 31, 2023) was:

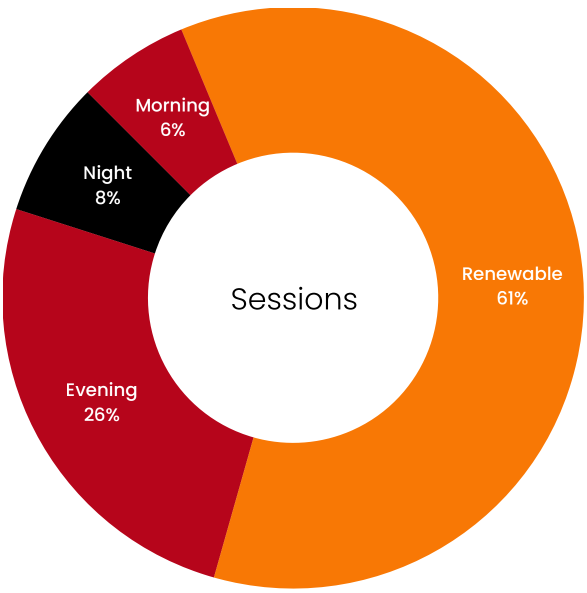
Experiment cycle two results
1 Jul – 31 Aug 2023

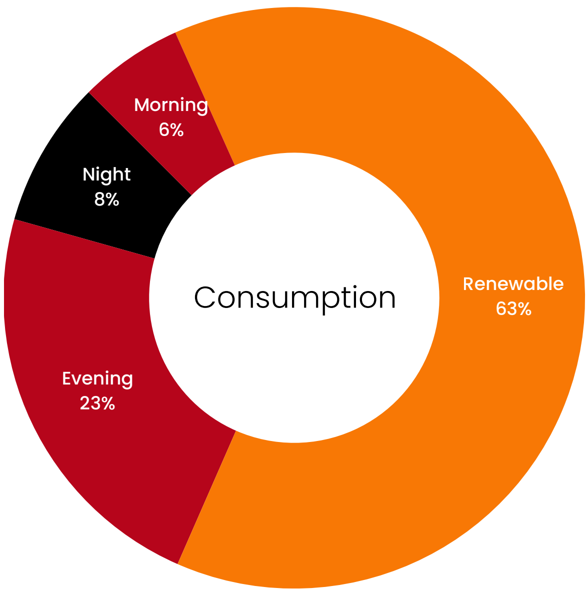
Sessions
595
15% increase

Consumption
19482 kWh
17% increase

Median consumption
32.8 kWh
0% Change

Measure	Morning	Renewable	Evening	Night
Number of sessions	21	327	121	48
Total consumption	664.89 kWh	10852.42 kWh	3465.61 kWh	1683.84 kWh
Median consumption, per session	29.10 kWh	33.23 kWh	27.75 kWh	37.29 kWh
Total session duration	792 mins	12763 mins	3907 mins	1776 mins
Median session duration	40 mins	40 mins	30 mins	34 mins
Total cost to driver	$378.14	$954.52	$876.88	$385.74
Median cost to driver, per session	$18.01	$2.92	$7.25	$8.04





As per the previous experiment cycle, to rule out seasonal variation in the data recorded we compared consumption and usage at Port Adelaide Plaza with a number of similar stations across Australia. The results at Port Adelaide Plaza continued to trend above what may be seasonally expected at similar periods due to lower rooftop solar generation potential and consequent constraints on home charging for drivers with rooftop solar systems.

Over this time period, other charge stations were coming online in the vicinity of Port Adelaide Plaza. This did not seem to have an outsized effect on the popularity or usage pattern of drivers, possibly due to usage being restricted by location and time. The fastest of these stations were rated at a shared power of 50 kW.

Implications

After modest price changes, usage patterns remained constant and consistently above seasonal trends, delivering a consistent, high rate of consumption during grid-friendly times. The pricing change delivered an additional benefit: a marginal increase in generated revenue for site hosts.

Measure	Baseline	Cycle one	Cycle two	Cycle three
Full-fee paid charge sessions	64	204	269	219
Discounted charge sessions	127	321	355	297
Total revenue to site host	$1000.33	$2595.28	$6920.76	$6994.19
Average revenue generated per charge session	$5.24	$5.02	$11.63	$13.66

Table 3. Revenue generated by charge sessions

Queueing

We began to observe a new problem, however: **queueing**.

Our pricing strategy was creating a charging bottleneck during low-cost, grid-friendly times. Drivers were waiting longer to charge and/or leaving without charging. This is partly due to the configuration of the station: most of the time, only the station's CCS2 plug was in use. On average, the CHAdeMO plug was being used once a month.

Cycle	Morning	Renewable	Evening	Night	Total
Experiment Cycle One	3	148	13	2	166
Experiment Cycle Two	1	148	21	5	175
Experiment Cycle Three	1	99	18	4	122

Table 4. Instances of queueing

Cycle	Morning	Renewable	Evening	Night
Experiment Cycle One	18	18	9	20
Experiment Cycle Two	46	16	17	14
Experiment Cycle Three	24	11	21	2

Table 5. Median queueing times, in minutes.

Our analysis of usage patterns concluded that we had effectively maximised the station to capacity, with only a certain amount of charging possible on one plug during solar sponge periods.

Learnings for next experiment cycle

In the next experiment cycle, we wanted to see if we could address the queueing issue we were observing, while maintaining existing usage patterns, using a pricing strategy alone.

Experiment cycle three

Objective

Having achieved our objective of shifting charging consumption to grid-friendly times, we wanted to optimise charging during the 'renewable' period so that as many drivers could charge at the highest rate of charge possible during the period.

This meant that, during the renewable period, we wanted to:

- reduce the median duration of a charge session
- discourage drivers from charging beyond sufficiency (80% state of charge)
- keep 'dwell' or idle time to a minimum, e.g. the period of time in which a driver may be plugged in, but not charging

After an extensive period of design and analysis, with potential interventions weighed up against the time, effort and cost to deliver, we believed the most straightforward way of testing our hypotheses around reducing charge session duration and discouraging overstays was to add a **per-minute fee for charging** during the 'renewable' period.

Pricing Strategy

From 1 September to 31 October, a pricing strategy was applied to the station which altered the previously applied pricing strategy by offering 'free' kWh during the 'Renewable' period and charging a per-minute fee instead:

Morning	Renewable	Evening	Night
energy demand: 5am - 9am $0.90 per kWh	generation: 9am - 4pm $0.00 per kWh + $0.18 per min	energy demand: 4pm - 10pm $0.90 per kWh	low demand: 10pm - 5am $0.45 per kWh

Charge session data captured for this period (September 1 to October 31, 2023) was:

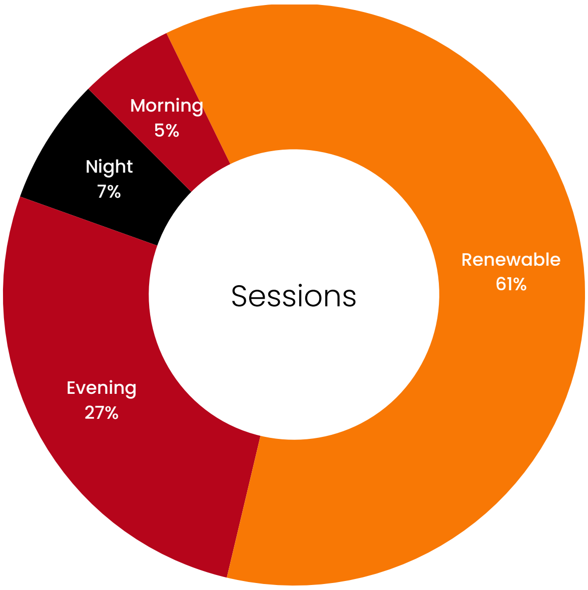
Experiment cycle three results
1 Sep - 31 Oct 2023

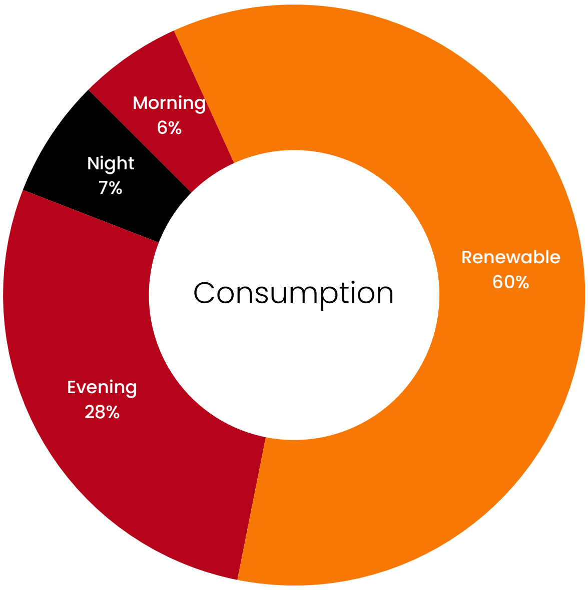
Sessions
512
14%
decrease

Consumption
16428 kWh
16%
decrease

Median consumption
33.3 kWh
2%
increase

Measure	Morning	Renewable	Evening	Night
Number of sessions	27	312	137	36
Total consumption	939.14 kWh	9841.59 kWh	4561.78 kWh	1085.32 kWh
Median consumption, per session	36.62 kWh	32.46 kWh	35.06 kWh	30.52 kWh
Total session duration	908 mins	11276 mins	4955 mins	1259 mins
Median session duration	33 mins	36 mins	38 mins	31 mins
Total cost to driver	$240.47	$1518.65	$1090.87	$317.37
Median cost to driver, per session	$8.91	$4.87	$7.96	$8.82





In the last week of Experiment Cycle Three, a second DC fast charging station was installed at the other end of the Port Adelaide Plaza carpark. At this stage of the experiment cycle, results were already pointing to a decrease in overall usage, however - we believed that enough of a trend had been established by this point to minimise the new station's impact on charging data.

Implications

The median length of a charge session at Port Adelaide Plaza has consistently been 36 to 38 minutes throughout the course of the Trial. Consumption peaks at the beginning of a charge session, and trails off toward the end, particularly after EVs are 80% charged or more.

We wanted our pricing strategy to have the effect of reducing median session time and discouraging drivers from charging beyond 80% unless absolutely necessary. In spite of a generally positive reception in the press[13], the pricing strategy applied in this Experiment Cycle did not have the desired effect.

Over the timeframe of the experiment cycle, we saw no change to median session duration. Queueing did reduce slightly, but this was due to lower patronage overall.

This result may be explained by the findings of our second round of qualitative research, which we completed toward the end of the cycle. In this research, we discovered that drivers have a strong preference for per-kWh pricing, as they have learned how to estimate both the duration and cost of a charge session based on this unit of value.

Further, per-minute pricing is perceived as less reliable (and even 'unfair') to drivers, as the duration of a charge session is often outside of a driver's control. We also learned that drivers will trade 'price certainty' with 'low cost': if a pricing strategy is too complex or ambiguous, drivers aren't able to estimate the cost of charging and will choose charging stations with more straightforward and/or familiar pricing.

We believe the above factors are responsible for the overall drop in patronage and shift in consumption, with drivers choosing certainty and familiarity. Consequently, when the Experiment Cycle concluded, we reverted pricing back to the strategy used in Experiment Cycle Two, as it had produced the most successful outcome.

13 See https://thedriven.io/2023/09/07/the-120kw-ev-fast-charger-that-is-free-for-the-day-time-solar-soak as an example

Follow-up driver interviews

Objective

Across the Chargefox network, pricing strategies are becoming more complex and multi-faceted. It is possible for station owners to set a price per kWh, per minute, or a combination of both units. These prices can be further modified by the time of day at which a charge session begins, or by the total duration of the charge, e.g. one per-minute or per-kWh price can be set for the first 30 minutes of charging, and a second per-minute or per-kWh price can be set for charging beyond 30 minutes. Some of this functionality was purpose-built for the Smart Charging Trial to ensure maximum flexibility in the experiment phase of the project.

Considering the increased complexity of the pricing strategy applied at Port Adelaide Plaza, we wanted to establish the limits of an EV driver's ability to predict how much a charging session (to 80% or above) might cost them. We also wanted to understand if there was any correlation between the complexity of a pricing strategy and an EV driver's decision-making when it comes to charging in public, e.g. station selection, charging duration, etc.

Approach

We conducted 60-minute interviews via Google Meet with 8 EV drivers. We presented a number of alternative design treatments of the 'Location details' screen within the Chargefox app.

Each design treatment included a representation of the pricing strategy currently applied at Port Adelaide Plaza (Experiment 3), which had a time-based component, a per-minute component, and a per-kWh component.

This pricing strategy represented a significant degree of complexity, which challenged current app design patterns. We wanted to understand whether an alternative design pattern existed that could make the pricing plan clear to drivers – or whether the plan itself needed to be simplified.

Interview participants

Of the 8 respondents selected for interview:

- 8 were EV owners who had recently charged at a public charge station
- 8 were South Australian residents
- 8 owned an electric vehicle and used it as their primary vehicle
- 4 identified as male
- 4 identified as female

The average age of participants was 66.

7 of 8 participants were able to charge at home. These participants reported using the public charging network occasionally for convenience ('want to charge' instead of 'need to charge'), but reported having to sometimes rely on it for mobility, e.g. in the course of a long-distance drive ('need to charge' vs 'want to charge').

One participant who was not able to charge at home was entirely reliant on the public charging network for mobility. The participant would make a special weekly trip to select and use a public charging station to top up their car for the week.

Findings

Overview

We found that EV drivers have a strong preference for per-kWh pricing (vs per-minute pricing).

Drivers have learned to estimate the cost of charging based on the per-kWh price and the associated increase in range: per-minute pricing is perceived as ‘hard to predict’ as it is influenced by factors outside of a driver’s direct control, e.g. battery temperature, the variable rate of charge at a charging station, etc.

We found that offering a mix of per-kWh and per-minute pricing created significant confusion. Multi-faceted pricing made it hard for drivers to estimate how much it might cost to charge, as it was difficult for them to determine how both time and kWh pricing would be applied together. This was true regardless of the design treatments presented.

Drivers indicated that they would trade cost-saving for price certainty in such a scenario. They showed us that they would choose a charging station with ‘simple’ pricing that was consistent with their mental model, over a station whose pricing was more complex even though it might be cheaper to charge.

We believe drivers will choose a charging station that offers a familiar, ‘known’ pricing plan (even if it is more expensive) rather than risk charging at a charging station where the pricing plan is unfamiliar or ‘unknown’ to them (even if it might be cheaper).

Prospect Theory may partially explain and anticipate this observation (see below).

Planning to charge

Participants were familiar with the public charging options in their area and had learned over time to anticipate when stations might be free or busy. They told us that the availability of a connector influenced their charging decisions more than price.

For long-distance trips, the majority of participants reported using an app (PlugShare or A Better Route Planner) to plan their route in advance, and that mobility mattered more than price, e.g. drivers cared more about having the range to get to their destination on time, rather than how much it might cost them to charge at a particular station.

This implies that long-distance drivers are not inclined to 'shop around' for a cheaper price if they're on the road, further validating findings from earlier research. As more charging options become available along well-travelled routes in future, this may change.

Station selection

Aligned with earlier findings, participants articulated four main factors that influenced station selection for top-up charging:

- the availability of the charging station, e.g. is it busy, is it working?
- the speed of the charging station
- the location of the charging station, e.g. is it close to me or to where I want to be?
- the per-kWh price of charging

Participants told us that availability was of paramount importance to them. They weighed their chances of being able to charge by the number of connectors a station has (more connectors = more desirable), the time of day they were considering charging, past experience at similar stations and general perceptions of a station's reliability.

In alignment with findings from the first round of interviews, participants described price as the least important factor in choosing where to charge, with the caveat that the price needed to fall within an acceptable and anticipated range and that the pricing plan was immediately understandable to them.

Broadly, participants told us they preferred charging at a station they had charged at before, particularly if they'd had a positive experience there. This may be due to drivers having experiences of arriving at a charge station to find it out of order or otherwise unavailable to them.

"If you're travelling 100km you want to know if the charger at the end of your range is working"
PARTICIPANT

"Will it tell me the station is out of order? They frequently are in my experience."
PARTICIPANT

Per-kWh vs per-minute pricing

We asked participants about their experiences with a per-minute price for charging, and whether they had a preference for per-minute or per-kWh pricing.

Participants preferred per-kWh pricing, as it allowed them to more reliably estimate how much a charge session might cost them. They told us they believed that, as the duration of a charge is determined by factors outside of their control, eg. a car's state of charge, the temperature of the battery, the available rate of charge at the station, etc. it seemed 'unfair' for them to be charged by the minute. A per-kWh price was seen as straightforward and tangible by contrast:

> *"You want 40kWh, you pay for 40kWh. You know … what you're going to get"*
> PARTICIPANT

> *"If I need to put 100kW in, how long is it going to take me?"*
> PARTICIPANT

When asked about mixed-pricing strategies that combine both per-kWh pricing and per-minute pricing, participants told us they would rather pay a per-minute price than a combination of the two, but that ultimately per-kWh pricing by itself was their preference.

Idle fees

We also explored 'idling' or 'dwelling' with participants: this is defined as being connected to a station but not drawing a charge from it, which prevents others from using the connector to charge. We discussed potential strategies for discouraging 'idling.'

Participants unanimously supported the introduction of an idle fee, and preferred this strategy to increasing the per-minute price of charging after a set period of time.

The value of simplicity

We presented participants with the pricing plan applied at Port Adelaide Plaza, and gave them the opportunity to compare it to other stations in the vicinity with simpler pricing plans.

We asked, based on what participants estimated or understood it might cost them to charge, which station they would choose and why.

100% of participants indicated that they would choose a station where pricing was clear to them over one where it was not. This sentiment remained true even after we showed them calculations indicating that the more complex pricing strategy was, in fact, cheaper. The effort required to estimate the cost of a charge outweighed any savings that might be realised as a result:

“I would be picking between the second and the third one but I'd be sitting down to actually calculate the cost and the time and work out which bit was free.” (User 5)

“It's like trying to work out the cheapest electricity company - I spend my whole day working it out and I've only saved $100!” (User 6)

‘Renewable’

We received feedback on the term ‘Renewable’ which broadly aligned with feedback received from our initial driver survey.

Overall, participants understood that ‘Renewable’ meant ‘solar and wind energy is abundant at this time of day.’ Participants were broadly aware of South Australia’s outstanding renewable energy generation capability, and were familiar with incentives and messaging that encouraged people to shift their energy usage to the middle of the day.

“I live in Adelaide, we sometimes run completely off of renewable and they often want us to use the sun at certain times” (User 4)

Prospect Theory

Prospect Theory (Kahneman and Tversky) shows that people are more likely to take risks to avoid a loss (loss aversion) relative to a person’s reference point , than they are to pursue an uncertain gain above that reference point. It also shows that the absolute outcome of a decision is less important than the perceived loss or gain against a person’s reference point.[14]

14 Kahneman, Daniel; Tversky, Amos (1979). "Prospect Theory: An Analysis of Decision under Risk" (PDF). Econometrica. 47 (2): 263–291. CiteSeerX 10.1.1.407.1910. https://doi.org/10.2307/1914185.

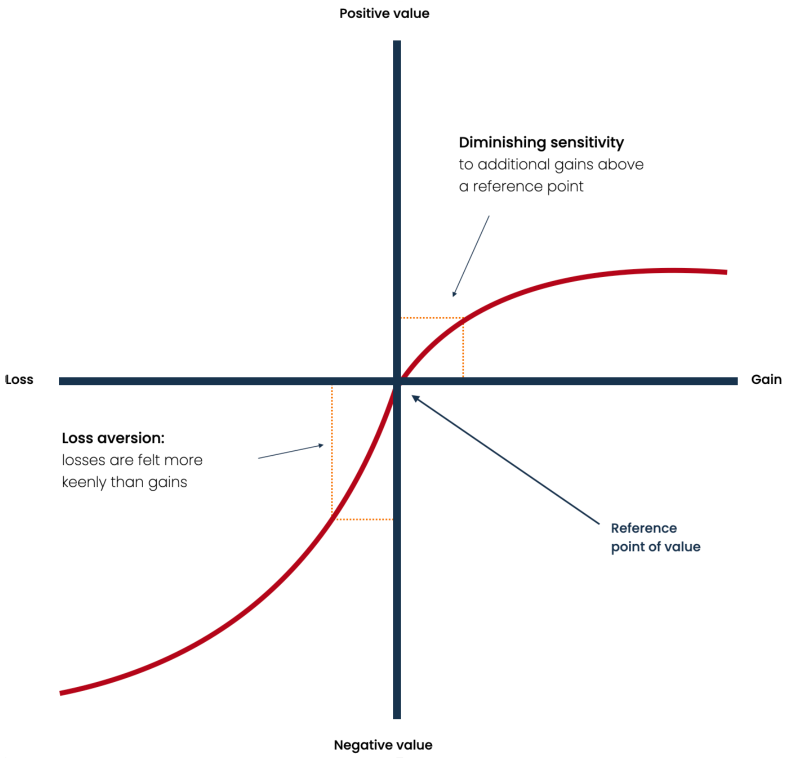


Fig 23. Prospect Theory

In a recent Chinese study, Bao et al[15] introduced Prospect Theory to assist in modelling time-of-use pricing strategies, and proposed that EV drivers use both the state of charge of their vehicle and the price of charging as the reference point by which to determine the value and utility of a charging session.

Our theory is that:

- EV drivers may be more likely to take risks to avoid an insufficient state of charge (resulting in a loss of mobility, e.g. 1% to 30% state of charge) than they are to maintain a sufficient state of charge (gain of charge, e.g. 50% - 80% or above)

- Consequently, EV drivers who have a low state of charge, or who do not have sufficient range to reach their destination ('need to charge'), may risk paying a higher charging cost to secure the mobility they require. In this scenario, a price signal may have little to no influence on their behaviour.

- EV drivers who are simply topping up ('want to charge') may be marginally more price-sensitive, as they have the flexibility to choose where and how much to add to their state of charge. In this scenario, however, they are consolidating a gain, meaning they may be less likely to take risks and will prefer certainty over cost-saving.

15 Bao, Y.; Chang, F.; Shi, J.; Yin, P.; Zhang, W.; Gao, D.W. An Approach for Pricing of Charging Service Fees in an Electric Vehicle Public Charging Station Based on Prospect Theory. Energies 2022, 15, 5308. https://doi.org/10.3390/en15145308

Summary of findings

Initial hypothesis

We formed an initial hypothesis based on available insights and assumptions about the motivations and decision-making processes of electric vehicle drivers.

We believed that, as drivers were generally not price-sensitive, a price signal would not be capable of influencing them to shift their charging to 'Renewable' periods in the middle of the day. We believed that other interventions would need to be employed to achieve the Trial's desired outcome.

Surprising results

In Experiment Cycle One, we applied an 'extreme' pricing strategy to Port Adelaide Plaza. We set a competitively low price per-kWh for a 'Renewable' period between 9am and 4pm, and made charging during periods of peak energy demand ten times more expensive.

We observed that, contrary to our hypothesis, electric vehicle drivers were responding to our price signal and shifting their charge sessions to the 'Renewable' period. Moreover, overall patronage at the station increased above both seasonal trends and the growth in electric vehicle ownership.

To understand the cause of these observations, we conducted quantitative and qualitative research with electric vehicle drivers in the form of a survey and two rounds of driver interviews.

Charging station choice

Electric vehicle drivers ask themselves four key questions when choosing when, where and whether to charge at a public charging station:

- How urgently do I need to charge?
- Will the charging station be working and available?
- Will I have to wait to use it?
- How long will it take me to charge (and what will I do while I'm waiting)?

The estimated cost of charging, and the associated per-kWh price of charging, is a secondary concern. Should drivers answer the above questions satisfactorily and arrive at a shortlist of public charging stations, they will then price-compare by estimating total cost using the published per-kWh price.

'Need' vs 'Want'

We defined two behavioural segments among respondents and participants: 'want to charge' and 'need to charge' drivers.

'Need to charge'

'Need to charge' drivers are those who face a loss of mobility due to a low state of charge, insufficient range to reach their destination, or an inability to charge at home.

Drivers who 'need to charge' are **extrinsically motivated** to charge in public: factors outside of their control are compelling them to use a public charging station.

'Need to charge' drivers are not price sensitive as they will risk paying more to avoid a loss of mobility. Their ability to plan ahead may be limited, which in turn limits their ability to choose the location and cost of their next charge.

'Want to charge'

'Want to charge' drivers are those with a sufficient state of charge and/or range. They have more flexibility to choose both the location, speed and cost of their charge. Drivers who 'want to charge' are **intrinsically motivated** to charge in public

While 'want to charge' drivers are marginally more price-sensitive (as they have the flexibility to price-compare), they prefer certainty over cost-saving: all other factors being equal, they will choose public charging stations with clear, easy-to-estimate pricing strategies over complex, hard-to-understand pricing strategies.

An electric vehicle driver can exhibit behaviours consistent with either of these segments, depending on their situation.

“Price of charging” mental model

The electric vehicle drivers we spoke to expect to see a per-kWh charging rate that is commensurate with their home energy rate, plus a reasonable margin that covers the cost of infrastructure, plus a 'convenience premium' that applies to fast charging (roughly, ‘fast’ means a charging station capable of a rate of charge above 25 kW):

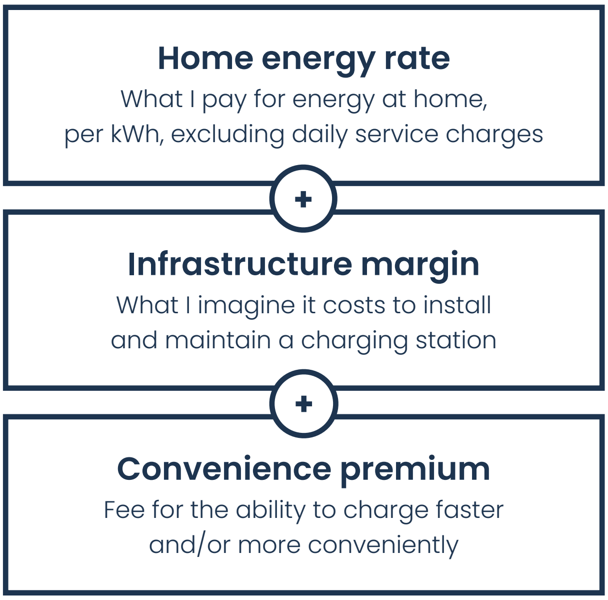


Fig 25. ‘Price of charging’ mental model

The ‘goldilocks zone’ of pricing

In absolute terms, electric vehicle drivers set both an upper and lower limit on the price of charging.

Pricing that approached the per-litre price of petrol was considered ‘too high’.
It was considered to be ‘price gouging.’ Drivers believed ‘too high’ pricing served as a disincentive to electric vehicle ownership.

Pricing that approached ‘free’ was considered to be ‘too low.’ Drivers believed this increased the likelihood of a charging station being overly busy and unavailable, and encouraged queueing. They also believed it served as a disincentive for charge point operators and site hosts to install more charging stations, as sustainable revenue could not be generated by them. The general scarcity of public charging stations was front-of-mind to drivers.

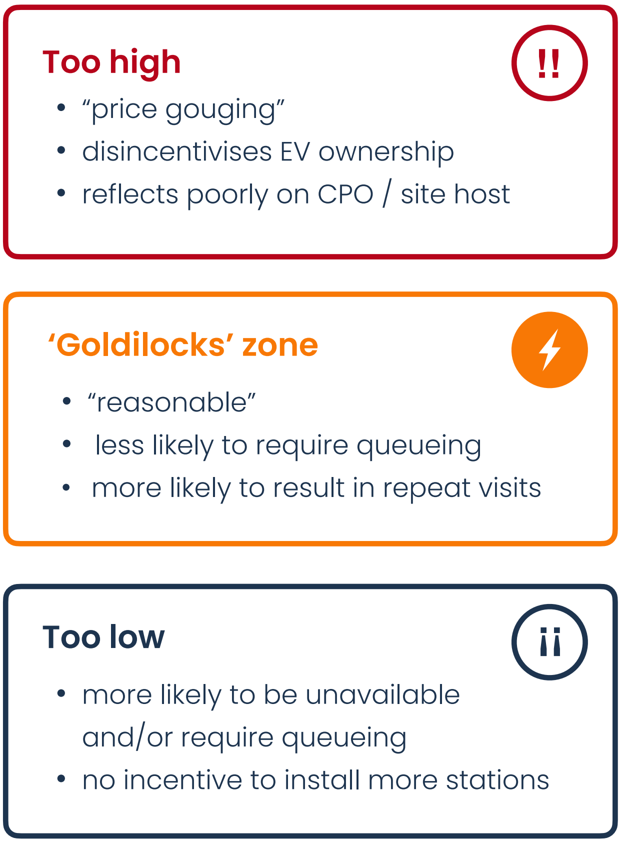


Fig 26. 'Goldilocks zone' of pricing

Tweaking the price signal

In Experiment Cycle Two, we used our understanding of a driver's 'price of charging' mental model to tweak the pricing strategy applied at Port Adelaide Plaza.

We increased the price of charging during 'Renewable' periods by 50% and reduced the price of charging during peak energy demand periods to be five times (rather than ten times) more expensive.

We observed no change in usage patterns over the experiment period and concluded that the new pricing strategy continued to be effective at encouraging drivers to charge during the 'Renewable' period while delivering additional value to the charging station operator.

We did observe an increase in instances of queueing, however.

Unintended consequences

In analysing both charge session data and CCTV camera footage, we learned that, by the end of Experiment Cycle Two, we had effectively maximised the charging station's ability to meet demand during the 'Renewable' period. This was due to there being only one CCS2 connector installed at the station: the other connector, a CHAdeMO plug, was rarely used.

In Experiment Cycle Three, we turned our attention to ways in which we might maximise consumption from existing charge sessions during the renewable period. We sought to do this by decreasing median charge session duration and increasing throughput: as charge sessions draw the most power at the beginning of a session, if we could encourage drivers to stop charging at sufficiency (80%), more vehicles would be able to charge per hour. This would have the additional benefit of reducing the number and length of queueing incidents.

To achieve this, we applied a pricing strategy which set a price per-minute for charging during the 'Renewable' period, rather than a price per-kWh.

Per-kWh pricing is preferred

The results of Experiment Cycle Three were disappointing: not only did we observe a slight drop in patronage at the charging station, we also saw a shift in consumption away from the 'Renewable' period and back toward periods of peak energy demand.

To help us explain this, we conducted another round of qualitative research and learned that:

- Participants preferred per-kWh pricing, as it allowed them to more reliably estimate how much a charge session might cost them. They told us they believed that, as the duration of a charge is determined by factors outside of their control, eg. a car's state of charge, the temperature of the battery, the available rate of charge at the station, etc. it seemed 'unfair' for them to be charged by the minute

- 'Want to charge' participants, unable to estimate the cost of charging, were not prepared to risk using a charging station whose cost was unknown to them in order to consolidate their sufficient range or state of charge

Consequently, we developed a theory to explain the results of the experiment cycle:

- Because the pricing strategy applied to Port Adelaide Plaza during the 'Renewable' period was too complex, electric vehicle drivers were not able to accurately estimate the cost of charging their vehicle

- 'Want to charge' drivers who charged at Port Adelaide Plaza were less likely to risk what they perceived could be a higher cost, and either selected a different charging station or shifted their consumption to periods in which the cost was better understood (albeit higher in absolute terms) during the morning and evening peak.

Conclusion: price signals work, with caveats

Over the course of this Trial, our exploratory research indicates that a price signal may be effective at encouraging electric vehicle drivers to consolidate their charging at public charging stations during periods of peak renewable energy generation, with the following caveats:

- a per-kWh pricing strategy is applied
- the pricing strategy is simple and easy for a driver to understand, with limited facets and a clear gap between 'high' and 'low' pricing
- the pricing strategy aligns with a driver's 'price of charging' mental model
- the pricing strategy falls within a driver's 'goldilocks' zone of reasonableness
- the charging station meets or exceeds other desirability criteria, e.g. availability, reliability, speed, convenience

Commerical implications

This research has shown that charging station operator may be able to realise positive revenue gains by offsetting per-kWh price *decreases* during periods of peak renewable energy generation with per-kWh price *increases* during periods of peak energy demand.

While we did not directly factor in the retail cost of electricity incurred over the course of this Trial, we broadly believe it is possible for charging station operators to implement time-of-use pricing strategies in a way that achieves (at least) net-neutral revenue outcomes.

Chargefox's clients independently set and manage the pricing strategies for the stations they own and operate on our network. The results of this Trial may be of interest to them.

Scarcity as a factor

Across both rounds of qualitative research, in surveys and in internal Chargefox research, drivers have repeatedly expressed a strong desire for more (and more reliable) public charging options - and they want more 'fast' charging stations in particular.

This implies that there is currently a perception among electric vehicle drivers that fast, reliable public charging stations are scarce.

Considering that the Port Adelaide Plaza charging station came online at a time when public fast charging stations were even less available in the Adelaide metropolitan area than they are at present (as of the writing of this report), we believe that scarcity may have been a factor in the results observed through the course of this Trial.

Current 'early adopter', 'want to charge' electric vehicle drivers who have the flexibility to choose the time, location and cost of charging may have been incentivised to drive 'out of their way' to Port Adelaide Plaza not only because the charging station met all of their desirability criteria and was relatively cheap, but also that there were few other options available.

As more fast charging stations become available in more locations, the strength of time-of-use price signals may diminish as other factors (particularly convenience) take precedence in a driver's choice of charging station – unless a universal pricing approach is considered.

Recommendations

To assist with managing demand across the electricity network, we recommend a limited implementation of time-based pricing, within the following parameters:

- **Limit time-based pricing to locations where the highest potential impact to consumption exists.**
  There is a cost to increasing the complexity of pricing strategies. Confused drivers can always choose another charging station, or to charge at home instead

- **Apply time-based pricing to fast DC charging stations (25 kW or above) only**
  This will deliver the most effective outcome from a consumption perspective (highest potential impact) and is this worth the trade-off of increased pricing complexity

- **Apply time-based pricing only to DC fast charging stations frequented by "I want to charge" drivers who are topping up and have the flexibility of choice.**
  These drivers are developing habits that are within their ability to change. In contrast, drivers charging at rural superchargers have limited capacity to change their charging behaviour and simply 'need to charge' when they arrive

In terms of designing the pricing strategy itself, we recommend the following:

- **Keep it simple.**
  Implement time-based per-kWh pricing only, for a limited number of time periods (ideally 2, no more than 4). Drivers have come to understand per-kWh pricing and have developed strategies to translate kWh to range and the estimated cost of a charge. Drivers consider per-minute pricing as difficult to estimate, as the duration of a charge is dependent on factors outside of a drivers' control (some see it as 'unfair').

- **Consider introducing idle fees.**
  Today's 'early adopter' drivers are supportive of charging a fee for drivers who 'idle' or remain connected longer than they need to be. Considering the scarcity of fast charging stations in particular, these fees will help increase throughput during periods of renewable generation and establish positive public charging habits

- **Establish a reasonably large difference between peak and off-peak pricing.**
  This sends a clear signal to drivers who are otherwise not price-sensitive. For the trial, we established that a 5:1 ratio between 'renewable' and 'peak demand' periods was sufficient to drive behaviour while not being seen as 'price gouging'

- **Set pricing that falls within a drivers' pricing model - no higher or lower.**
  Drivers have developed a model for the price of charging based on the per-kWh price of electricity they pay at home, plus an infrastructure levy and an additional levy for convenience (on fast charging stations in particular). Pricing plans which are deemed 'too high' based on this value model are seen as unfair 'price gouging', while pricing which is deemed 'too low' decreases the prospects of connector availability and is perceived as a disincentive to install more charging stations (which is ultimately what drivers want)

- **Ensure there are enough connectors, and that connectors are of the right type.**
  At Port Adelaide Plaza, we quickly hit a physical limit on the number of charge sessions that were possible during solar sponge periods, as the charging station was equipped with one CCS connector, and one CHAdeMO connector that was rarely in use. To increase consumption at grid-favourable times, two CCS connectors would have had a greater impact

- **Consider augmenting 'destination' DC charging locations with multiple AC charging stations to alleviate queueing and encourage patronage.**
  By adding supplemental AC charging stations, drivers who 'want to charge' but may not need a fast charge to top up will still have charging options and a reason to visit the 'destination.' This may potentially free up a fast charging station for those with a low state of charge who 'need to charge'. It also presents opportunities to set a meaningful, comparable price for speed and convenience within a single location

- **Charge extra for speed, but never limit the capacity of a fast charging station.**
  Drivers were against limiting the capacity of a fast charging station, considering the scarcity of fast charging in general. The concept of speed-limiting was received very negatively and considered a waste of infrastructure, effort and investment.

- **Explore queue management options.**
  Considering the time and cost required to install a charging station, demand for public charging stations will outstrip supply for some time to come, creating queueing at times of peak usage. If queueing cannot be avoided, and grid operators continue to seek to encourage drivers to charge within a limited time-window, solutions will be required to alleviate poor queueing experiences. As previously stated, most EV drivers have the option of charging at home instead - poor queueing experiences may discourage drivers from charging in public at any time of the day. Consider both software and physical, space-based solutions to alleviate the pain of queueing.

Appendices

Publicly accessible data

The following data is available for public access:

- **Smart Charge Trial Driver Survey - all respondents who had registered in the Chargefox app with a South Australian postcode** (de-personalised, web format): https://pwegii69qrx.typeform.com/report/RixdWGbK/KpWIERRtV4YSGiCo

- **Smart Charge Trial Driver Survey - respondents who had charged at a Port Adelaide charge station at least once** (de-personalised, web format): https://pwegii69qrx.typeform.com/report/ZBpUKmCB/0jSYkboPAKO35kFW

- **Smart Charge Trial Driver Survey - all respondents, tagged** (de-personalised, spreadsheet format): https://docs.google.com/spreadsheets/d/1MJ7rYDsrCxBG3TkC1E-21mt7Q13AYDdw9a7qme9AmWU/edit?usp=sharing

- **Charge station usage data** for the time-period of the trial (6 December 2022 to 6 December 2024), in spreadsheet format to view or download: https://docs.google.com/spreadsheets/d/1gr0qQ1ICH0qY1tLcoZvLLQBvaDnScyCVJRKwpSD_pHo/edit?usp=sharing

Appendices

Terminology used in this document

Definitions of the following terms have been adapted from the NRMA's EV glossary, unless otherwise noted. The full glossary can be found here: https://www.mynrma.com.au/electric-vehicles/basics/ev-glossary

AC

Alternating current (AC) is the type of power that we use in our homes. Electric cars use direct current (DC) in their operation, meaning AC power needs to be transformed into DC power before it can charge an electric car.

Charging stations that run on AC power take longer to charge a car's battery than more powerful DC charging stations, leading some to call AC charging stations 'trickle' or 'slow' chargers.

CCS2

CCS2 is a type of connector or 'plug' used by electric vehicles. It stands for 'Combined Charging System 2' and is becoming one of the most common connector types for electric vehicles in Australia. CCS2 connectors allow for fast charging of electric vehicles at DC charging stations.

CHAdeMO

"CHAdeMO" is an abbreviation of "CHArge de MOve." It is a pun on "O cha demo ikaga desuka" in Japanese, meaning "Let's have a cup of tea while charging." Many Japanese-made EVs in Australia have a CHAdeMO connector for DC fast charging.

Charging station

A charging station is hardware that electric vehicle drivers use to charge the battery of their vehicles. Each charging station has one or more connectors for vehicles to plug in to. Charge stations are rated by their power output in kilowatts (kW), and can supply either AC or DC power. A 'fast' or 'ultrafast' charging station is a DC charge station that can recharge a vehicle's battery in less than an hour, and sometimes less than 15 minutes.
A 'slow' or 'trickle' charging station is an AC charge station with a lower power output.

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DC

DC refers to Direct Current. This type of energy is used for the operation of electric vehicles. ‘Fast’ charging stations output DC power, meaning they can transfer electricity directly into an electric vehicle’s battery without it needing to be transformed by the vehicle’s onboard inverter. The result of this is higher, more efficient charge rates and faster charging, compared to those of AC-powered ‘slow’ charging stations.

Electric Vehicle (EV or BEV)

EV stands for ‘electric vehicle’ – a term which encompasses any and all vehicles that use electricity to move. In this report, ‘EV’ refers specifically to electric motor vehicles. ’BEV’ includes ‘battery’ in the acronym, but refers to the same type of vehicle.

Fast charging

According to the Electric Vehicle Council, a ‘fast’ charging station is defined as any DC charging station with a power output between 25kW and 350 kW. This means that EVs using a ‘fast’ charging station can fully charge their car battery in under an hour, with some faster stations able to fully charge a car in under 15 minutes.

See https://electricvehiclecouncil.com.au/a-z-charging/ for more information about different types of EV charging stations.

ICE, ICE’d and ICE’ing

ICE stands for Internal Combustion Engine, which is any engine that relies on the combustion of a fuel in a chamber to produce energy. This includes petrol, diesel, LPG and hydrogen.

To be ICE’d means to have an internal combustion engine vehicle block an EV from accessing a charging station, usually by parking in an EV charging bay.

Kilowatt (kW)

A kilowatt (kW) represents 1000 watts of energy and is the most common metric used to measure power. When it comes to EVs, ‘kW’ is used in two instances: the maximum power output of a vehicle’s electric motor(s); and as a measure of the rate of charge a charging station is capable of.

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Kilowatt hour (kWh)

Unlike the kilowatt (kW) – which is an instantaneous measurement of power – a kilowatt hour (kWh) is a measure of energy capacity, or power over time. kWh is used to measure the capacity of a battery in an EV. The larger this kWh figure, the more energy the EV can store. The majority of charging stations set a per-kWh fee for charging electric vehicles, as this has a direct relationship to an electric vehicle's range.

'Public' vs 'private' charging

Charging stations are said to be 'public' when they are available for use by any electric vehicle driver with no restriction to access. 'Private' charging stations are those with restricted access, e.g. for use only by those who live in an apartment complex, or stations who are behind a gate or barrier. Some stations are both public and private, eg stations that can only be used by employees during business hours, but available to the public outside of these hours.

Range and 'range anxiety'

Driving range is how far an electric vehicle can travel on a single charge, expressed in kilometres (kms). 'Range anxiety' describes a driver's state of mind when they are concerned about not having enough 'range' in their vehicle to reach their destination.

Site host

In Chargefox terminology, a 'Site Host' is the owner / proprietor of a location that hosts one or a number of charging stations. Any charge session revenue raised by a Site Host's stations is collected by Chargefox and reimbursed to the Site Host, minus a small management and administration fee.

State of charge (SoC)

Measured between 0 and 100 per cent, the state of charge (SoC) of an electric vehicle refers to remaining charge in the vehicle's battery. It is crucial information for EV drivers both on the road and at charging stations, as it determines the range of the vehicle. SoC is displayed on an electric vehicle's dashboard. Some vehicle manufacturers recommend only charging a battery to 80% of its capacity to maintain battery health.