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Research Article

Planning for the majorities: are the charging needs and preferences of electric vehicle early adopters similar to those of mainstream consumers?

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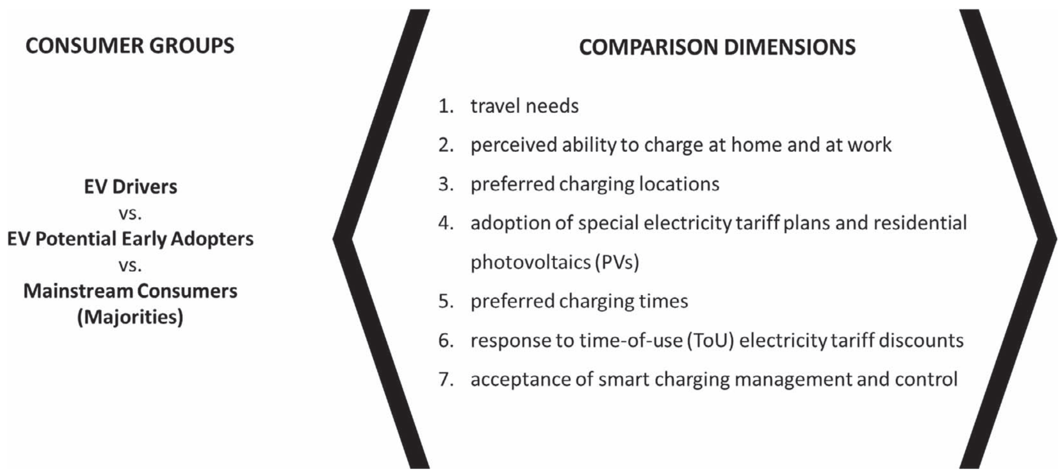
Abstract

The mass deployment of electric vehicles (EVs) may bring significant challenges to the electricity sector. However, many of these challenges can be converted into opportunities depending on how and when consumers decide to charge their vehicles. While there are currently multiple efforts worldwide investigating EV charging behaviour, these efforts measure the behaviour of EV early adopters and may not represent the actual behaviour of the mainstream consumer. The current study uses data from a survey with near a thousand Australian consumers to shed light on the potential similarities and differences between the charging needs and preferences of EV early adopters and mainstream consumers. We find that consumer groups vary in terms of charging needs, perceived access to residential charging, and acceptance of direct charging control and management by suppliers. Our conclusions point to (i) the need for campaigns that increase the awareness and understanding of residential EV charging by mainstream consumers; (ii) the significant interest across all consumer groups in free workplace charging, which could together with residential demand management strategies leverage the use of solar energy for charging; and (iii) the need for utility plans and management strategies that enhance the mainstream consumer sense of control over charging together with their perceived monetary savings.

Graphical Abstract



Lay Summary: This study analyses data from a survey with near a thousand Australian consumers to investigate potential similarities and differences between the charging needs and preferences of current electric vehicle owners and future mainstream consumers. Our conclusions point to (i) the need for campaigns that increase the awareness and understanding of residential electric vehicle charging by mainstream consumers, (ii) the significant interest across all consumer groups in free workplace charging and (iii) the need for utility plans and management strategies that enhance the mainstream consumer sense of control over charging together with their perceived monetary savings.

Keywords: smart charging, diffusion of innovations, Australia, demand management, consumer behaviour, electric vehicle charging, electric vehicles

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INTRODUCTION

Electric vehicle (EV) sales have been rapidly increasing worldwide and, even under the COVID-19 pandemic, the global electric car stock had a 43% growth in 2020 [17]. Despite this upward trend, almost all EV markets are still experiencing the early adoption phase, with Norway being the only country to pass the 15% EV stock share [18]. While such market evolution suggests that EVs are here to stay, it provides very little insight into how usage and charging will look like when EVs become mainstream.

Mainstream adoption of EVs is expected to bring both challenges and opportunities to the electricity sector, requiring immediate planning for the long-term adaptation. Challenges are mostly associated with potential increases in peak loads if demand management strategies are not put into place and users decide to charge their vehicles at localized points in space and time. On the other hand, if effectively managed, EVs create the opportunity to solve the timing imbalance between peak demand and renewable energy production. That is, EVs can leverage their storage capabilities by charging during off-peak (or excess generation) times and providing electricity to residences, as well as micro and macro grids, during peak periods.

Considering that both the challenges and the opportunities posed by EVs are heavily dependent on user behaviour, there is a major need for the electricity sector to understand the charging needs and preferences of the mainstream consumer [30]. While there are currently multiple efforts worldwide aiming at capturing charging profiles through trials, these efforts measure the behaviour of EV early adopters or consumers who are borrowing an EV for the trial purpose and thus may not represent the actual behaviour of the majority of the consumers. Given that both theoretical and empirical literature point to significant differences between market segments based on the different phases of uptake of a new technology [6, 9, 26, 27, 29], it is necessary that the charging behaviour literature identifies whether these differences may result in heterogeneity in consumer charging preferences, choices and electricity use profiles.

In this context, the current study sheds light on the potential similarities and differences between the charging needs and preferences of EV early adopters and mainstream consumers and discusses the implications of these relationships to planners. In specific, we compare consumer groups in seven dimensions: (i) travel needs, (ii) perceived ability to charge at home and at work, (iii) preferred charging locations, (iv) adoption of special electricity tariff plans and residential photovoltaics (PVs), (v) preferred charging times, (vi) response to time-of-use (ToU) electricity tariff discounts and (vii) acceptance of smart charging management and control. We use data obtained in an online survey with Australian EV drivers and internal combustion engine vehicle (ICEV) drivers in mid-2021.

In the remainder of this paper, Section 2 presents the theoretical and empirical background for this research, which is followed by the description of the data collection and analysis methods. The results and the discussion of the comparison between consumer groups regarding the seven identified dimensions are described in Section 4. In Section 5, we compare our results with those observed in previous studies discussing potential relationships with EV market maturity and we reflect on limitations of our study suggesting future research directions. Finally, we present the main conclusions and recommendations.

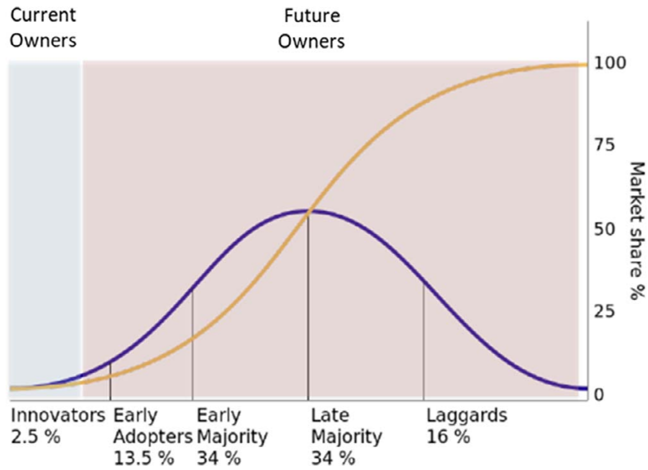

Figure 1. EV adoption in Australia in comparison with the diffusion of innovations curve (adapted from [29])

BACKGROUND

In this section, we provide a brief overview of the theory that proposes the categorization of adopters based on innovativeness [29]; then, we discuss the current and prospective EV owner profiles reported in the national and international literature. Finally, we summarize major findings in the EV literature comparing early adopters with mainstream consumers, noting the lack of empirical evidence on charging preferences and the seven dimensions analysed in the current study.

The theory: diffusion of innovations

The diffusion of innovations theory proposed by Rogers in 1962 uses the individual trait of innovativeness to divide consumers into five technology adopter groups: innovators, early adopters, early majority, late majority and laggards, as shown in Fig. 1. These groups are said to vary in terms of psycho-social (e.g. personality traits and socio-demographic) and motivational (e.g. perceived symbolic value) characteristics. For instance, innovators can usually understand complex technical knowledge and are risk takers with high social status and financial liquidity (being able to cope with the uncertainty and potential losses associated with the early stage innovations). While early adopters also have high social status and financial liquidity, their lifestyles are more associated with opinion leadership and central communication positions. Majority groups do not have the same level of financial liquidity and thus tend to make decisions based on utility and practicality, being more cautious before committing to the purchase of new products. They usually become adopters when the new technology provides substantial economic advantage and/or there is significant peer pressure [29].

While Rogers' market segmentation based on innovativeness may be considered limiting in some instances [6], it is unarguable that when aiming to transition a product from the early adoption stages to a larger market share (mainstream consumers), marketers and business developers need to take into consideration the heterogeneity in economic power and motivations of consumers. Similarly, when trying to understand and predict usage patterns of EVs, planners from the energy and transport sector need to recognize that the behaviour they observe from early adopters may not represent that of mainstream consumers. For example, while innovators and early EV adopters may consider multiple factors (such as environmental benefits) when deciding how and when to charge their vehicles, the majorities may be more heavily driven by economic benefits [6, 37].

The consumer: who is currently buying EVs?

In Australia, Europe and the USA, survey results show that current EV owners are typically men approaching middle age who have high incomes and education and are part of family households. They also tend to be homeowners who can charge their cars at home, have relatively high annual kilometrage and more than one car available in their households [1, 10, 16, 23, 31, 33]. For instance, in Norway, 75% of the households with EVs also have an additional car; the numbers are even higher for the UK and California, with 80% and 94%, respectively. Yet, in most of these multi-car households, the EV is used as the main car [23].

While in an immediate future, most new buyers are likely to be people with same or similar demographic characteristics of current buyers, insights from the Californian and Nordic markets show that the relationship between age, income, gender and EV ownership is weakening [23, 31]. In California, Lee *et al.* [23] identified that from 2012 to 2017 the fastest growing socio-demographic group of EV owners was of middle-income individuals who lived in multi-unit buildings (2.1%–7.9% market share). While this was the fastest growing socio-demographic group, most EV owners in the state still had high incomes and resided in a detached dwelling (where off-street parking usually facilitates residential EV charging).

The literature: differences in motivations and behavioural profiles

Differences between early adopters and mainstream consumers have been explored by several studies investigating purchase intention and determinants of EV adoption [6, 26–28, 37]. On the other hand, this type of differentiation is less evident in the EV charging behaviour literature (see reviews by [15] and [22]). To the authors' knowledge, only Axsen and colleagues compared pioneers and mainstream consumers regarding their access to residential charging and interest in controlled charging programs [6, 7]. Based on data from Canada and the USA, these authors concluded that EV early adopters are more likely to have access to off-street parking and residential chargers, especially Level 2 chargers. Additionally, the authors observed that even though early adopters place almost five times more value on using renewable electricity to charge their EVs than the early majorities, they are less accepting of controlled charging and would require higher compensations to join such programs.

Differences in consumer psychological traits and motivations identified in the EV adoption research may also shed light on potential charging behaviour differences between consumers. In particular, mainstream consumers are observed to have higher levels of traditional values and resistance to change than early adopters, giving more importance to the equivalence of performance between current ICEV and EV technology [6, 26]. Therefore, the majorities are more likely to have an expectation that charging stations are as common as petrol stations and that recharging are as fast as refuelling an ICEV. Further, they are probably less accepting of other new technologies that accompany EVs and involve behavioural change, such as the use of smart chargers and time-dependent tariff schemes.

In terms of individual motivations, the evidence in the literature points to three segments of consumers among early adopters and the majorities. The first group is driven by technology innovativeness, while the other two groups are driven by the environmental and economic benefits of EV technology [6, 26–28, 37]. Earlier studies tended to associate pro-technological and pro-environmental attitude to early adopters, and interest in financial aspects to the majorities, corroborating Rogers' theory [26, 28]. Yet, more recent studies suggest that there are significant variations on the degree of these motivations across the majorities, requiring further market segmentation. For instance, European studies show that the consumer segment that has the strongest environmental inclination is yet to adopt EVs because they travel shorter distances and current usage savings do not compensate the higher purchase cost of EVs [27, 37]. These findings indicate that travel needs, technology adoption and charging preferences should be investigated as part of a joint package of choices associated with consumer lifestyles. Further, they point to the need for further examination of similarities and differences between (and within) EV early adopters and mainstream consumers.

MATERIALS AND METHODS

This study analyses data from an online survey that elicited preferences and behaviours of Australian car owners regarding EV charging. As discussed in Section 2, consumers are expected to differ in terms of psycho-social and motivational characteristics depending on where they fall under the technology adoption curve. However, their level of experience using EV technology may also play a significant role in shaping their charging preferences and behaviour. That is, an individual who already drives an EV is likely to have different charging perceptions than one who is still in the purchase research phase. Therefore, to examine the differences between EV early adopters and mainstream consumers, while also considering technology experience, we segment current car owners into three categories: current EV drivers, potential early adopters or PEAs (car owners planning to purchase an EV within 1 year of the survey date) and the majorities (car owners not planning to buy an EV within 1 year of the survey date). [Note that the 'majority group' of consumers could be further segmented depending on the timeframe in which respondents planned (or not) to purchase an EV (e.g. 5 or 10 years). We did test creating these segments but, in general (and as also observed by [6]), no consistent differences were observed, which led to a single 'majority group'.] The survey results are analysed descriptively using contingency tables and pairwise Chi-square tests when applicable. That is, we compare the observed frequencies of the variables of interest between EV drivers and PEAs, and between PEAs and the majorities when at least five observations per cell are available.

Because of the low penetration of EV ownership in Australia (<1% of the passenger vehicle fleet), we consider as EV drivers those who currently drive either a battery electric vehicle (BEV) or a plug-in hybrid vehicle (PHEV). BEVs do not have internal combustion engines (ICEs) and run solely using battery power, which is obtained via external charging plug. A PHEV, on the other hand, has both an ICE and a battery-powered motor and can be recharged via external plug. While fully charged PHEV batteries can provide driving ranges of around 50 km (based on car models available in Australia [11]), users can also rely on the ICE for travel. In this sense, the charging behaviour of BEV and PHEV owners may be very different, as the first group has longer range batteries that need to be recharged and the second has shorter range batteries that have the option of being recharged via external plug. Considering this difference, we discern these two groups as much as possible throughout our analysis but are unable to test their differences statistically due to sample size limitations.

In the following sections, we describe the sampling and participant recruitment strategy, the survey design and the data processing and sample description.

Survey sampling and recruitment

In 2021, there were almost 15 million passenger vehicles registered in Australia, but only 20 000 of these were EVs [2]. Considering this low incidence of EV ownership, a random sample of vehicle owners in Australia would not allow for an investigation of EV owners' preferences and behaviours. Therefore, this study sought to collect data from two independent samples, totalling 1000 responses. Sample 1 targeted at 900 responses from ICEV drivers, while Sample 2 aimed to reach 100 EV drivers. Screening questions were used to ensure that 'drivers' were individuals 18 years or older, with a valid driver's license and living in a household that owned at least one car. EV drivers not only had to own an EV, but they also had to be the person in the household to predominantly use and charge it.

Sample 1 was exogenously stratified to ensure national representativeness relative to Australia's adult population (driving age) in terms of age, gender and gross household income. The socio-economic stratification was defined based on the distribution of age, gender and household income of the adult population of Australia as these socio-demographic profiles are not available for the specific population of car owners. This approximation is acceptable considering that Australia has, on average, one car per adult and only 7% of Australian households do not own a car [3]. Non-interlocking socio-demographic quotas for Sample 1 were obtained using filter questions at the beginning of the online questionnaire and then weights were applied to the final sample for fine adjustments. Sample 2 did not target any socio-demographic distribution as the profile of the EV owner population of Australia is unknown.

The survey was distributed between July and August 2021 by a market research panel aggregator company, Qualtrics, which recruited and compensated participants. Online sample providers maintain a list of potential survey participants (email or user-id list) and utilize weighted randomization techniques (based on the desired socio-demographic attributes) to send out survey invitations to potential respondents. Even though the invitation process can be considered probability-based, this sampling approach still suffers from frame coverage bias and selection bias. That is, only individuals who are capable and willing to join online market research panels are reached (frame coverage bias) and those who are invited can accept or reject survey invitations and opt-out while taking the survey (self-selection and non-response bias). Recruitment strategies aimed to minimize self-selection bias by omitting any information about the survey topic from the recruitment material. The use of sample providers cannot be considered a flawless probabilistic sampling approach but allows for better socio-demographic distribution coverage than other convenience sampling techniques. The above limitations should be considered by policy recommendations based on this study's results.

Questionnaire design

The survey questionnaire contained six main sections, including (i) filter questions (to ensure the target population and specified quotas were met), (ii) travel information (to understand charging needs and constraints), (iii) EV ownership and purchase intention (to segment consumers into different adopter groups), (iv) residential and workplace parking and charger availability, (v) general charging preferences and (vi) residential charging management preferences and attitudes. EV owners also answered additional questions about their usual charging behaviour.

Before answering Sections 5 and 6, respondents who did not own an EV were requested to consider a hypothetical scenario where they owned a BEV and were able to charge it in their residences. The charging location preference questions were accompanied by estimates of charging rates (kilometres per hour of charge) of usual charger levels available in different places. The rates provided were (i) dedicated fast-charging facilities would charge 225 km per hour of charge, (ii) workplace and other destination chargers would charge 45 km per hour of charge and (iii) residential chargers would charge 20 km per hour of charge.

Finally, in Section 6, respondents were introduced to the idea of smart chargers and charging management and control. The following definitions were provided.

- *Types of chargers*
  - Conventional chargers do not include a data connection.
  - Smart chargers include a data connection.
- *Options for controlling the charging and managing your costs and electricity demand*
  - Unmanaged conventional charging. Charging is monitored and controlled only by you. Your car is charged from the moment it is plugged in (or based on a simple timer). The rate of charge is fixed based on your charging point specification (e.g. 20 km per hour of charge) and costs depend on your electricity plan and the times you choose to charge.
  - User-managed smart charging. Charging is optimized by an automatic system that is monitored and controlled only by you. You provide the system with the desired level of charge and your next departure time, and the system will automatically select the cheapest time to charge your car based on ToU tariffs. The rate of charge may be lower than your charging point specification to minimize costs. If you need to use your car before your set departure time, it may not have the desired level of charge.
  - Supplier-managed smart charging. Charging is optimized by a centralized system that communicates and coordinates with the electricity supplier to determine the best schedule for your charge considering real-time electricity demand in your area. You provide the system with the desired level of charge and your next departure time, and the system will automatically select the cheapest time to charge your car based on discounts that vary to help balance the overall demand for power in your area and increase the share of renewable energy used. The rate of charge may be lower than your charging point specification to minimize costs and balance the demand. If you need to use your car before your set departure time, it may not have the desired level of charge.

Respondents had to first select their preferred charging control and management option, and then answer a series of attitudinal questions (five-point Likert scale) regarding supplier-managed smart charging, including perceived risks and benefits. To avoid respondent learning bias, the entire questionnaire was designed with a gradual degree in question specificity. The most general questions were presented at the beginning and the most specific at the end.

Table 1. Sample socio-demographic distributions

	EV drivers	BEV drivers	PHEV drivers	ICEV drivers	Potential early adopters	Majorities
Gender						
	($n = 100$)	($n = 52$)	($n = 48$)	($n = 897$)	($n = 174$)	($n = 723$)
Female	30.0%	26.9%	33.3%	50.7%	41.1%	53.0%
Male	70.0%	73.1%	66.7%	49.3%	58.9%	47.0%
Age						
18–24	15.0%	15.4%	14.6%	11.9%	16.4%	10.8%
25–34	21.0%	13.5%	29.2%	19.6%	36.6%	15.5%
35–44	53.0%	53.8%	52.1%	17.7%	17.9%	17.6%
45–54	8.0%	13.5%	2.1%	16.6%	15.1%	17.0%
55–64	1.0%	0.0%	2.1%	15.4%	8.3%	17.1%
65–84	2.0%	3.8%	0.0%	18.8%	5.7%	21.9%
Gross annual household income[a]						
$1–34 999	2.0%	3.8%	0.0%	17.2%	7.2%	19.6%
$35000-99 999	4.0%	0.0%	8.3%	40.1%	33.1%	41.8%
$100 000 or more	94.0%	96.2%	91.7%	42.7%	59.7%	38.6%
Employment status						
Full-time	91.0%	90.4%	91.7%	40.5%	56.3%	36.8%
Part-time	6.0%	3.8%	8.3%	21.7%	25.9%	20.6%
Unemployed	0.0%	0.0%	0.0%	6.6%	6.3%	6.7%
Not in the work force	3.0%	5.8%	0.0%	31.2%	11.4%	35.9%

[a]The three income categories represent the low income, middle-low to middle income and middle-high to high income household groups in Australia according to the segmentation by the Australian Bureau of Statistics [4].

Sample weighting and data description

The final clean sample contained 997 observations, of which 100 were from EV drivers. For ICEV drivers, sample weights were calculated using an iterative proportional fitting (raking) method to adjust the stratification quotas of gender, age and gross annual household income that were not met [19]. Geographic variables and interactions between variables were not considered in the weighting process due to the small sample size. The weighted ICEV driver sample was segmented into the groups of PEAs ($n = 174$) and the majorities ($n = 723$) based on their intention to purchase an EV.

Table 1 presents the socio-demographic distributions of the collected samples and subsamples. While the distributions of ICEV drivers follow the national proportions, we see that, compared with the majorities, PEAs are more likely to be male, younger, high-income and full-time employed individuals. Except for the age attribute, this is the same profile observed for current EV owners both in our sample and in previous studies [16, 23, 31].

RESULTS

This section presents the contingency tables comparing the consumer groups in regard to the seven dimensions of interest: (i) travel needs, (ii) perceived ability to charge at home and at work, (iii) preferred charging locations, (iv) adoption of special electricity tariff plans and residential PVs, (v) preferred charging times, (vi) response to ToU electricity tariff discounts and (vii) acceptance of smart charging management and control. The tables show differences between BEV and PHEV drivers but pairwise Chi-square tests are conducted only to evaluate differences between the EV driver group (BEV + PHEV) and PEAs and between PEAs and the majorities because of sample size limitations. If any cell in the columns of interest contains less than five observations, the test cell is marked as Not Applicable (N/A).

Travel needs

We compare the travel needs of the different consumer groups by analysing their weekly distances driven and commute distances (Table 2). While there is no evident difference between the travel needs of BEV and PHEV drivers, these groups drive almost twice as much as the national Australian average (extracted from [2]), with 61% of EV drivers travelling more than 290 km per week. We observe a progressive decrease in distances driven as we compare EV drivers with PEAs and the majorities. Only 34% of PEAs drive more than 290 km per week, while this share decreases to 18% among the majorities. Similar trends are observed in terms of one-way commute distances for the sub-samples of commuters within the groups. These results are aligned with evidence that individuals who drive longer distances are willing to pay more for vehicles (see, e.g. [21]). They may also indicate that the currently higher purchase cost of EVs may be appealing only to those who will benefit the most from lower running costs (because charging is currently cheaper than petrol refuelling). The major implication of this result to the energy sector and utility providers is that weekly charging needs per capita are likely to decrease as the adoption curve reaches the majorities. Therefore, projections based on current EV charging trials may overestimate required charging loads.

Ability to charge at home and at work

Considering that residential parking in the form of driveway, carport or garage allow for easier access to charging outlets than car parks and street parking [22], we compared the three groups of consumers regarding their residential parking arrangements and did not observe statistically significant differences (Table 3). However, in terms of parking distances to power outlets, there seems to be a difference in the level of awareness of current EV owners compared with potential consumers. The share of EV owners that stated that power outlets are located more than 10 m away from the parking spot is a lot larger than the share of

Table 2. Distributions of weekly distances driven and commute distances

	BEV drivers	PHEV drivers	EV drivers	Potential early adopters	Majorities
Weekly distance driven					
	($n = 52$)	($n = 48$)	($n = 100$)	($n = 174$)	($n = 723$)
<70 km	1.9%	0.0%	1.0%	14.4%	29.6%
70–150 km	9.6%	12.5%	11.0%	18.3%	25.0%
150–290 km	26.9%	27.1%	27.0%	33.3%	27.2%
>290 km	61.6%	60.4%	61.0%	34.0%	18.2%
Pairwise Chi-square test	N/A		N/A	χ^2 (3, $n = 897$) 32.94, $P < 0.001$	
Commute distance (sub-sample of commuters)					
	($n = 49$)	($n = 48$)	($n = 97$)	($n = 136$)	($n = 389$)
<10 km	4.1%	2.1%	3.1%	16.5%	33.2%
10–20 km	8.1%	18.8%	13.4%	28.5%	25.2%
20–33 km	24.5%	20.8%	22.7%	23.8%	24.8%
>33 km	63.3%	58.3%	60.8%	31.2%	16.8%
Pairwise Chi-square test	N/A		N/A	χ^2 (3, $n = 897$) 20.20, $P < 0.001$	

individuals that selected this option in the other groups. Instead, individuals in the PEA and majorities groups are more likely to state that they are unaware of the existence of electrical outlets near their parking location. Similarly, we observe that consumers' overall perception of their ability to charge at home increases with the level of interest and experience with EV technology.

In terms of workplace charging, current EV owners seem to be less likely to park their cars on the street, while parking patterns among PEAs and the majorities are similar. Yet, like the residential charging case, perceived access to charging points at the workplace seems to increase with the level of knowledge about EVs. It is interesting to notice that around 70% of consumers in all groups are interested in substituting residential charging by free workplace charging on a frequent basis. This result points to the significant potential that workplace charging can have as a demand management strategy, not only to shave evening peak consumption but also to increase the utilization of solar energy (as many vehicles are parked at work locations during the day).

Charging location preferences

Consumer charging location preferences were measured by asking survey participants to rank four places from the most to the least convenient: home; workplace (only for commuters); parking lots of shopping, dining, sporting and recreational facilities; and dedicated fast-charging facilities. Respondents were prompted to consider that chargers were available at all locations and approximate charging speeds were provided, as described in Section 3.2.

We observe that, for all consumer groups, on average, residential charging is preferred over the other options, while destination charging (i.e. parking lots of shopping, dining, sporting and recreational facilities) is perceived as the least convenient location (Fig. 2). On average, the convenience of using a workplace charger and a dedicated fast-charging facility seems to be perceived by all groups as equivalent. Despite the similar trends, the percentage of respondents to select residential charging as the most convenient alternative for the majorities group was significantly higher than the other groups. This result indicates that understanding the charging process and feeling confident about their ability to charge at home will be essential for this group to transition into electric propulsion technology, as observed in previous studies [15].

EV drivers also reported their monthly use of each one of these charging locations. On average, BEV drivers in the sample charge at home every other day (around 17 times per month). The average usage of workplace chargers and fast public-chargers is twice a week (9–11 times per month). These results show that the frequency of use of each location is aligned with convenience perceptions.

Residential PVs and electricity tariff plans

PEAs and the majorities are currently less likely than BEV drivers to have residential PVs and to subscribe to green energy and ToU electricity tariff plans. However, when asked if they planned to install PVs and/or subscribe to special tariff plans after purchasing an EV, PEAs demonstrate similar or greater adoption proportions to what is currently observed among BEV drivers, while the majorities are less interested in such features (Fig. 3). Based on the Chi-square tests, considering a situation where all consumer groups own EVs, there is no statistical difference between the three groups in terms of intended levels of ownership of solar panels. However, PEAs are more likely to adopt ToU, green energy and EV specific tariffs (χ^2 [1, $n = 423$] 37.44, χ^2 [1, $n = 423$] 20.62, χ^2 [1, $n = 423$] 34.84, respectively). The significant interest in green energy tariffs by PEAs corroborates with the European findings pointing to a group of environmentally conscious buyers ready to adopt EVs as purchase costs become more competitive [27, 37].

Considering that in 2021 30% of Australian residences had PVs [5], our results imply that an increase in the adoption of residential solar energy should be expected to accompany EV adoption. Further, while PEAs may be naturally inclined to seek ToU or EV specific tariffs, the majorities may require further nudging.

Residential charging start time

EV drivers reported the usual time that they start charging their vehicles at home, while potential consumers indicated their preferred start time. In Fig. 4, we observe that all groups present distributions that coincide with households' usual electricity consumption curves (small morning peak and pronounced evening peak).

Even though 82% of the EV drivers reported the ability to set a timer to start charging their vehicles, around 52% start charging between 16:00 and 21:59. Similarly, 51% of PEAs would also start charging during this period, while the proportion increases to 61%

Table 3. Parking availability, access to charger, perceived ability to charge, and response to free workplace charging

	BEV drivers	PHEV drivers	EV drivers	Potential early adopters	Majorities
Residential parking type					
	($n = 52$)	($n = 48$)	($n = 100$)	($n = 174$)	($n = 723$)
No off-street parking or car park	19.2%	18.8%	19.0%	23.3%	21.9%
Carport, garage, or driveway	80.8%	81.3%	81.0%	76.7%	78.1%
Pairwise χ^2 test	N/A		χ^2 (1, $n = 205$) 0.47, $P = 0.493$	χ^2 (1, $n = 897$) 0.96, $P = 0.757$	
Distance to power outlet					
No off-street parking	9.6%	4.2%	7.0%	14.3%	14.2%
Don't know	0.0%	0.0%	0.0%	8.5%	10.2%
<5 m	69.2%	33.3%	52.0%	47.8%	49.2%
5–10 m	13.5%	35.4%	24.0%	23.5%	17.6%
>10 m	7.7%	27.1%	17.0%	5.9%	8.7%
Pairwise χ^2 test	N/A		N/A	χ^2 (4, $n = 897$) 4.45, $P = 0.348$	
Perceived ability to charge at home					
No	1.9%	6.3%	4.0%	4.7%	19.1%
Maybe	0.0%	0.0%	0.0%	28.6%	32.2%
Yes	98.1%	93.8%	96.0%	66.7%	48.7%
Pairwise χ^2 test	N/A		N/A	χ^2 (2, $n = 897$) 26.93, $P < 0.001$	
Workplace Parking type (sub-sample of commuters)					
	($n = 45$)	($n = 42$)	($n = 87$)	($n = 118$)	($n = 305$)
Street parking	2.2%	11.9%	6.9%	19.2%	21.5%
Public or private car park	71.1%	73.8%	72.4%	71.4%	69.7%
Public or private garage	26.7%	14.3%	20.7%	9.4%	8.6%
Pairwise χ^2 test	N/A		χ^2 (2, $n = 205$) 9.86, $P = 0.007$		χ^2 (2, $n = 423$) 0.31, $P = 0.856$
Workplace access to EV charger (sub-sample of commuters)					
Yes	93.3%	88.1%	90.8%	27.7%	9.9%
No	6.7%	9.5%	8.0%	55.8%	83.2%
Don't know	0.0%	2.4%	1.2%	16.5%	6.9%
Pairwise χ^2 test	N/A		N/A		χ^2 (2, $n = 423$) 34.76, $P < 0.001$
Prefer to use of free workplace charging instead of residential charging (sub-sample of commuters that do not already use free charging at the workplace)					
	($n = 19$)	($n = 23$)	($n = 42$)	($n = 118$)	($n = 305$)
Always or most of the time	63.2%	78.3%	71.4%	69.7%	70.0%
About half of the time	5.3%	8.7%	7.2%	14.1%	13.9%
Sometimes or never	31.5%	13.0%	21.4%	16.2%	16.1%
Pairwise χ^2 test	N/A		N/A		χ^2 (2, $n = 423$) 0.01, $P = 0.998$

for the majorities. These results indicate the need for charging management strategies to nudge consumers into different charging times to avoid substantial increases in peak loads. Furthermore, they emphasize that the ability to use a charging timer and the adoption of special tariffs alone are not enough to flatten the demand curve, at least among current EV drivers.

Convenience and cost trade-offs and response to ToU tariff discounts

When asked about what is more important when making a charging decision, convenience and fast speeds versus low costs, current EV owners and potential consumers present opposite opinions. Around 51% of BEV drivers and 59% of PHEV drivers often or always make charging decisions based on the shortest charging time and the most convenient option, while only 21% of PEAs and 20% of the majorities would do the same. In contrast, 52% and 59% of those in the PEA and the majorities groups, respectively, would often or always choose the cheapest option over more convenient and faster options. These results reinforce the theoretical hypothesis that consumer sensitivity to monetary costs increases as the market expands and matures [29].

In addition to general preferences, the survey also elicited individual response to different residential ToU tariff discounts during mid-day (excess of solar energy production) and night (traditional off-peak) periods. Table 4 presents the percentages of respondents that stated to be 'extremely likely' to charge during the suggested time for each level of discount. We observe that

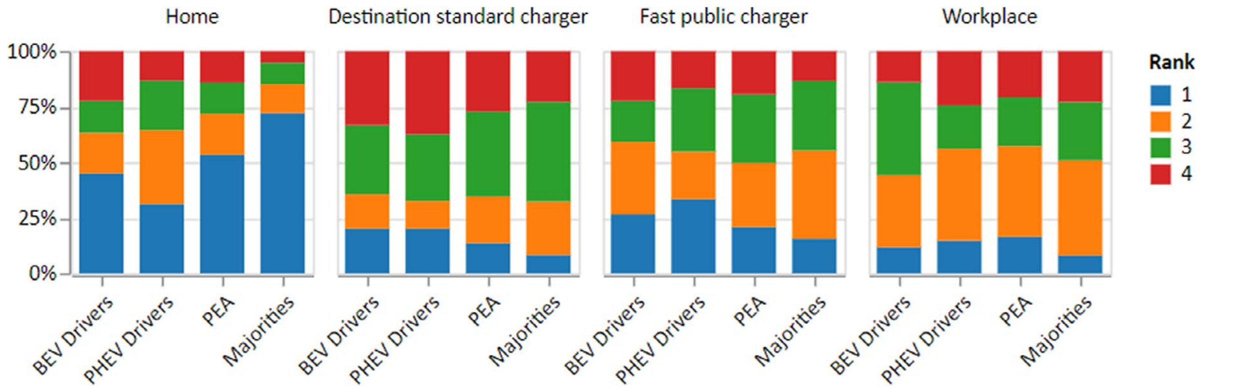

Figure 2. Charging location preference ranking from most (1) to the least convenient (4)

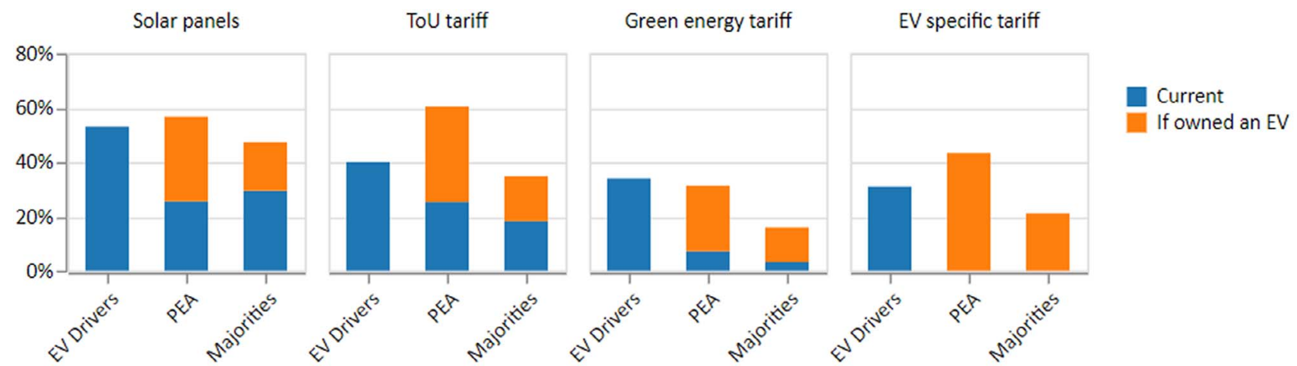

Figure 3. Current and potential adoption of PVs and residential tiered electricity tariff plans

current EV drivers are more likely to accept charging at off-peak periods without monetary savings (no discount), while potential consumers tend to show a stronger response to the 50% discounts. In specific, PEAs show the greater sensitivity to ToU discounts.

While there is an overall higher response to night discounts, mid-day discounts also show a significant potential to shift EV charging to off-peak periods, even when considering the share of consumers whose car is never home during mid-day periods (between 17% and 24%). (Data were collected while some Australian states were still imposing COVID-19 social distancing measures, which increased people's likelihood of staying home during the day. Therefore, the share of consumers whose car is never home during mid-day periods may be higher as social distancing measures wane and people resume to normal activity levels outside their residences. Yet, note that even individuals who work outside their homes and commute by car, may have their cars parked at home during non-workdays.) Overall, 44% of all consumers seem to be willing to charge during both mid-day and night off-peak periods in a 50% tariff discount scenario (with no statistically significant difference between EV divers, PEAs and the majorities). Even though these results seem promising, translating the general consumer acceptance of off-peak charging (in response to monetary savings) into actual daily charging behaviour is not trivial. Responsive behaviour may require new utility business models as well as the design of service pricing plans that make savings evident in a per day or per charge format [14].

Charging management preferences

Respondents were given three options of residential charging control and management (with definitions as described in Section 3.2) and asked to select their preferred alternative. While user-managed smart charging was the preferred alternative for most respondents in all groups (45%–49%, as shown at the top of Table 5), the share of respondents that preferred supplier-managed smart charging decreases from 42% to 30% and 24% when comparing EV drivers with PEAs and the majorities. This result somewhat contradicts the findings by Axsen *et al.* [6], in which EV early adopters were less accepting of controlled charging. One potential reason for this discrepancy (besides geographic and cultural differences) is the almost 10-year time difference between the data sets used in our and their study. Battery ranges have significantly improved over this period, which resulted in a decrease in range anxiety by EV users [22].

The overall acceptance of supplier-managed charging was also measured by asking users how likely they would be to adopt this technology in a generic scenario and in a scenario where a smartphone application could be used to override the third-party management and control as needed. Again, we observe an increase in scepticism towards supplier-managed smart charging as the consumer profile progresses in the EV adoption curve. Nevertheless, the overriding application feature shows a significant potential to increase the acceptance of supplier-managed smart charging among consumers, especially those in the majorities (from 34.7% to 56.2%).

Consumer attitudes seem to justify the observed supplier-managed charging acceptance statistics. While 66% of the EV drivers stated to feel comfortable passing over the control of when their car is charged to third parties, only 32% of the majorities feels the same way. Further, EV drivers are more likely (than PEAs and the majorities) to agree that a supplier-managed charging system will be better at reducing the use of non-renewable energy (compared with user-managed and unmanaged systems), which corroborates the findings by Axsen *et al.* [6]. While campaigns

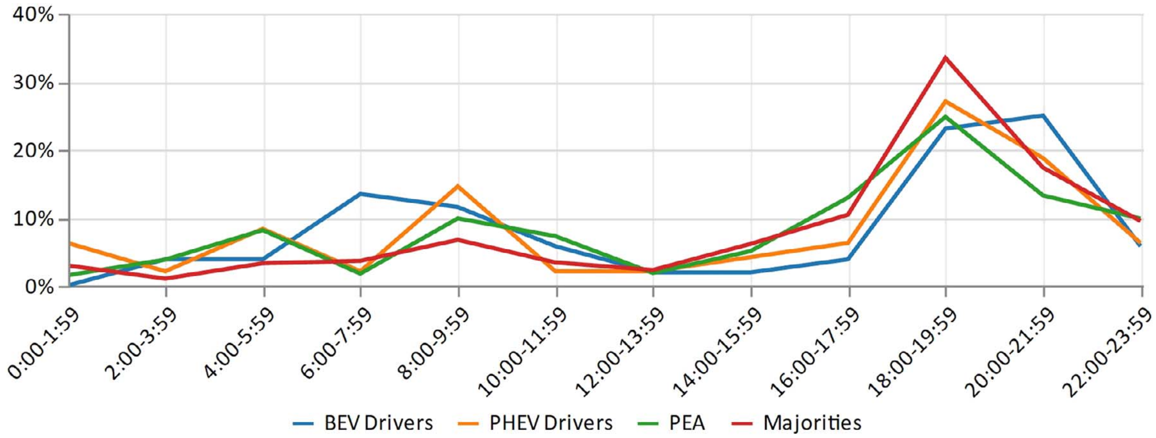

Figure 4. Distribution of usual charging start time for EV drivers and preferred charging start time for potential consumers (PEA and the majorities)

Table 4. Consumer response to ToU tariff discounts

	BEV drivers ($n=52$)	PHEV drivers ($n=48$)	EV drivers ($n=100$)	Potential early adopters ($n=174$)	Majorities ($n=723$)
Would start charging at 23:00 if					
No discount	25.0%	35.4%	30.0%	26.0%	21.8%
10% discount	25.0%	45.8%	35.0%	39.6%	26.6%
20% discount	32.7%	50.0%	41.0%	52.9%	40.3%
50% discount	75.0%	70.8%	73.0%	81.2%	78.2%
Would start charging between 10:00 and 14:00 if					
No discount	21.2%	16.7%	19.0%	20.1%	13.8%
10% discount	21.2%	27.1%	24.0%	30.2%	17.4%
20% discount	34.6%	35.4%	35.0%	39.0%	27.8%
50% discount	48.1%	58.3%	53.0%	60.1%	54.3%
My car in never home at this time	28.9%	18.8%	24.0%	16.6%	17.3%
Preferred charging start time considering a 50% tariff discount between 10:00 and 14:00 and 23:00 and 6:00					
10:00–14:00	11.5%	12.5%	12.0%	12.4%	10.3%
23:00–6:00	36.5%	22.9%	30.0%	30.1%	31.6%
Both	36.5%	45.8%	41.0%	47.7%	43.9%
Neither	15.5%	18.8%	17.0%	9.8%	14.1%
Pairwise χ^2 test	N/A		χ^2 (3, $n=274$) 3.32, $P=0.345$	χ^2 (3, $n=897$) 3.10, $P=0.376$	

targeting this attitude disparity and increasing user sense of control and perceived environmental benefits among the majorities may have some effect in improving the acceptance of supplier management, clear economic benefits are more likely to lead to a preference turning point for this group.

DISCUSSION

As markets mature, the charging needs and preferences of EV owners and potential consumers may vary geographically and temporally. While the EV market share is still low in most countries, some regions have been experiencing market growth for a much longer period than Australia. Nevertheless, based on a simple comparison of our results with those observed in previous studies, we verify that Australian consumer preference trends share general similarities with those from other countries in the past 10 years.

Table 6 summarizes the main findings of academic studies investigating the charging behaviour of EV owners (revealed choice) and charging stated preferences of EV owners and other consumer groups. Research that focused primarily on public charging preferences was considered out of scope. Studies are organized chronologically, based on the data collection year, and the dimensions of interest (1 to 7) are identified in the first column of the table. We briefly discuss how our results relate to those reported in the table, as well as findings from three literature review studies, Hardman *et al.* [15], Lavieri and Bas Domenech [22] and Sovacool *et al.* [30].

While a large-scale study in California, USA, did not observe differences between PEV, BEV and ICEV divers in terms of distances driven annually [32], European studies observed the same trend found in the current study that EV owners tend to drive longer distances than other groups [12, 37]. Rather than a market maturity difference, this result is likely reflecting the stronger

Table 5. Charging management preference and acceptance of supplier-managed smart charging

	BEV drivers (*n* = 52)	PHEV drivers (*n* = 48)	EV drivers (*n* = 100)	Potential early adopters (*n* = 174)	Majorities (*n* = 723)
Preferred charging management					
Unmanaged conventional charging	7.7%	12.5%	10.0%	21.2%	31.2%
User-managed smart charging	32.7%	64.6%	48.0%	48.6%	45.2%
Supplier-managed smart charging	59.6%	22.9%	42.0%	30.2%	23.6%
	N/A			$\chi 2$ (2, *n* = 274) 7.17, *P* = 0.027	$\chi 2$ (2, *n* = 897) 7.63, *P* = 0.022
Likelihood of adoption of supplier-managed smart charging					
Somewhat to extremely likely	88.5%	83.3%	86.0%	57.1%	34.7%
Neither likely nor unlikely	3.8%	12.5%	8.0%	26.0%	35.8%
Somewhat to extremely unlikely	7.7%	4.2%	6.0%	16.9%	29.5%
	N/A			$\chi 2$ (2, *n* = 274) 24.23, $P < 0.001$	$\chi 2$ (2, *n* = 897) 30.22, $P < 0.001$
Likelihood of adoption of supplier-managed smart charging with overriding-App feature					
Somewhat to extremely likely	90.4%	91.7%	91.0%	69.2%	56.2%
Neither likely nor unlikely	7.7%	2.1%	5.0%	20.4%	27.1%
Somewhat to extremely unlikely	1.9%	6.3%	4.0%	10.4%	16.8%
	N/A			$\chi 2$ (2, *n* = 274) 24.23, $P < 0.001$	$\chi 2$ (2, *n* = 897) 30.22, $P < 0.001$
I feel comfortable passing over the control of when my car will be charged to a supplier-managed smart-charging system.					
Somewhat to strongly agree	71.2%	60.4%	66.0%	50.7%	32.2%
Neither agree nor disagree	19.2%	31.3%	25.0%	19.3%	27.1%
Somewhat to strongly disagree	9.6%	8.3%	9.0%	30.0%	40.7%
	N/A			$\chi 2$ (2, *n* = 274) 16.18, $P < 0.001$	$\chi 2$ (2, *n* = 897) 20.80, $P < 0.001$
Supplier-managed smart-charging is better to reduce the use of non-renewable energy than other charging systems.					
Somewhat to strongly agree	86.5%	79.2%	83.0%	60.3%	53.1%
Neither agree nor disagree	11.5%	18.8%	15.0%	31.1%	37.9%
Somewhat to strongly disagree	1.9%	2.1%	2.0%	8.6%	9.0%
	N/A			$\chi 2$ (2, *n* = 274) 15.77, $P < 0.001$	$\chi 2$ (2, *n* = 897) 3.19, $P = 0.214$

car dependency in the USA, which leads to higher and more homogeneous driving rates.

Home is unanimously seen as the preferred charging location, not only by all consumers groups but also across all regions [12, 15, 22, 35, 36]. EV driver behaviour studies show that the workplace is the main charging location for those who cannot charge at home, while free workplace charging is also being increasingly used to reduce overall charging expenses in the USA and Canada [22, 23]. Our study expands this finding by demonstrating that both early adopters and mainstream consumers in Australia share similar preferences in this respect. Contrastingly, consumer differences in the ability to charge at home seem to vary across regions. While we observed that 4% of EV drivers and 19% of mainstream consumers cannot charge at home, the shares observed by Axsen *et al.* [6] in Canada were 3% and 34%, respectively.

Another consistent finding across the literature is the common preference to plug in EVs upon arriving home in the evening [12, 15, 24, 36]. However, the proportion of observed charging events during the evening peak is between 30% and 40%, indicating that off-peak periods are often used [20, 36]. There is a lack of academic literature investigating the effect of EV ownership on ToU plan enrolment and compliance, with some evidence available on reports from trials and non-profit organizations. For instance, a survey with 3000 EV drivers in the USA found that 65% of them adopted ToU tariffs, and 87% of these charged off-peak on almost every occasion (SEPA apud [22]). This penetration is similar to what we observe across EV drivers in this study if we consider both ToU and EV-specific tariffs together. Our findings also indicate that enrolment in ToU plans may be even higher among mainstream consumers if discounts near the 50% mark. While ToU plans that specifically target the mid-day period due to excess solar generation have not been explored by previous studies, European research shows that EV owners are more likely than ICEV owners to have residential PVs installed, which also corroborates our findings [12, 37].

While smart charging is a topic of growing interest, the technology is still incipient, and thus existing studies rely on stated choice experiments to extract consumer preferences. In this sense, it is difficult to discern if the inconsistent results are a result of hypothetical bias and variations of definitions

Table 6. International literature review summary organized chronologically based on data collection year

Topics	Citation	Region	Data type	Data year	Participant type	Main findings
5, 6	Khoo *et al.* [20]	Australia	Revealed choice	2013	EV trial participants	- Around 35% of the households started charging between 5 and 9 pm. Around 20% of the charge events began at 11 pm with another 5% starting later. This demonstrates that only 1/5 of participants saw a benefit in adopting ToU tariffs and that such a static tariff structure may lead to new peaks.
7	Bailey and Axsen [8]	Canada	Stated choice	2013	ICEV owners (potential early mainstream)	- Around 53% of ICEV owners interested and knowledgeable about EVs would voluntarily enrol in controlled charging but 38% were concerned about a loss of control. - Programs focusing on monetary gains for consumers would lead to higher participation in controlled charging than those focusing on the increase in renewable-based generation (63%–78% versus 49%–59% estimated participation).
2, 7	Axsen *et al.* [6]	Canada	Stated choice	2013	EV owners and ICEV owners (potential early mainstream)	- 3% of EV owners reported no home charging access, compared with 34% of ICEV owners. - ICEV owners interested and knowledgeable about EVs are slightly more accepting of controlled charging than EV owners. - EV owners placed five times as much value on using electricity generated from renewable sources than the ICEV owners.
5	Morrissey *et al.* [24]	Ireland	Revealed choice	2013–2015	EV owners	- Evening peak is the preferred charging time of EV owners.
7	Will and Schuller [34]	Germany	Stated choice	2015	EV owners	- Minimum range guarantee and ability to override are the most requested features to accept controlled charging. - Negative impacts of risk and privacy concerns on acceptance were not confirmed.
7	Nicolson *et al.* [25]	UK	Stated choice	2015	Electricity bill payers	- EV owners are more likely than ICEV owners to be willing to switch to user-managed smart charging.
1	Tal *et al.* [32]	California, USA	Revealed choice	2015–2018	EV (BEV and PHEV) owners	- On average, BEV, PHEV, and ICEV owners have similar annual distances driven.
1, 4	Zarazua de Rubens [37]	Denmark, Finland, Iceland, Norway, Sweden	Revealed and stated choice	2016–2017	EV owners and general public	- EV owners drove longer distances daily and were more likely to have residential PV installations than the general public. - The strongest EV interest was among very environmentally conscious consumers with a low willingness to pay for cars, indicating a latent demand waiting for a technology price drop.
2, 3	Lee *et al.* [23] (2020)	California, USA	Revealed choice	2016–2017	EV (BEV and PHEV) owners	- 37.8% of the BEVs and 30.5% of the PHEVs used more than one charging location per week, with home and work being the most frequent. More BEV owners than PHEV owners used workplace charging facilities. - 53% of EV owners only charged at home. - EV drivers substituted workplace for home charging when they paid high electricity rates at home, especially if the former was free.
1, 3, 4, 5, 6, 7	Delmonte *et al.* [12]	UK	Interviews	2017–2018	EV owners and ICEV owners with EV charging experience	- EV owners drove longer annual distances than ICEV owners. - Most common charging place was home followed by work. Work was the preferred charging place for those who could not charge at home. - Overall lack of interest in ToU, but still EV owners were more likely to have ToU tariffs. Most participants did not have a clear idea of their electricity costs and expenditures. - Most participants preferred to charge their vehicles at home in the early evenings as soon as they finished the last trip of the day. - User-managed charging based on ToU tariffs was preferred over controlled charging. Perceived barriers to engaging with controlled charging were trusting the supplier, loss of control (and freedom), and privacy concerns.
3, 5, 7	Wong *et al.* [36]	USA	Stated choice	2018	EV owners and ICEV owners	- 44% of EV owners charge at home every day; 31% charge as soon as they arrive home. - 23% of EV owners and 13% of ICEV owners would participate in controlled charging without any incentive. - A combination of monetary incentives, free charging equipment, and guaranteed battery level would be necessary to increase interest in controlled charging. - Participation interest decreases when there are penalties for overriding controlled charging.
3	[35]	Germany	Stated choice	2019	EV and ICEV owners	- For all respondents, the home was the preferred charging location, followed by work and then destination charging.

and experiment attributes or if they reflect actual consumer heterogeneity. For instance, corroborating our results, Delmonte *et al.* [12] found that both early adopters and mainstream consumers have a common preference for user-managed smart charging over supplier management or no management. In contrast, Nicolson *et al.* [25] observed that EV early adopters are more likely to accept user-managed smart charging than the general public.

Regarding controlled charging, there seems to be a common message that concerns about loss of control and privacy are major barriers to the acceptance of such programs [8, 12]. Nevertheless, these barriers can be reduced if programs guarantee users their minimum desired range and give them the ability to override control when needed [34, 36]. Finally, corroborating our findings, previous research in Canada and the USA identified that the environmental benefits of controlled charging may have a greater appeal to current EV owners than to mainstream consumers, and the latter may require more tangible monetary incentives to participate in these programs [6, 8, 30, 36].

Limitations and future research

Some considerations about limitations in the current study are important to guide future research efforts and to clarify caveats to policy recommendations. Measuring ICEV drivers' intentions regarding EV charging and eliciting preferences for emerging technology, such as smart charging, incurs hypothetical bias. While there are mechanisms that can help mitigate such bias [13], research results will naturally become more robust as the EV market matures and consumer awareness and knowledge about charging increases. As discussed in Section 3, even though consumers are expected to differ in terms of psycho-social and motivational characteristics depending on where they fall under the technology adoption curve, their level of experience using EV technology will likely have a significant influence on their charging behaviour. In this sense, a longitudinal study exploring differences between pre-purchase preferences and actual charging behaviour of mainstream EV drivers would generate important insights.

Our study also simplifies the measurement of behavioural variables that can be considered latent (such as attitudes, acceptance and intention) to single indicators. Future research should focus on more comprehensive scales and utilize factor analysis to have a more reliable measurement of such constructs. We also adopted a simplified stated preference elicitation approach, which did not enable the measurement of the relative importance of specific attributes that may characterize different types of ToU and smart charging programs. While some studies have investigated how consumers make such trade-offs using experimental designs, more research in this realm is necessary as EV markets develop and increased penetration of demand management strategies becomes essential.

CONCLUSIONS

This study conducted an empirical descriptive comparison of Australian consumer segments regarding their travel needs and EV charging perceptions and preferences. We find that EV early adopters and mainstream consumers vary in terms of charging needs, perceived access to residential charging and acceptance of direct charging control and management by suppliers. Several insights for utility suppliers, planners and policymakers can be drawn from the results.

Firstly, mainstream consumers seem to have lower travel needs than early adopters in terms of both weekly distances driven and one-way commute distances. Thus, charging needs per capita in Australia are likely to decrease as the adoption curve progresses towards the majorities. In this sense, utility suppliers should be aware that projections based on currently measured EV charging profiles and trial data may overestimate future energy needs per capita.

Secondly, even though our analysis does not test for causal associations, our results suggest that campaigns and other initiatives that increase the awareness and understanding of residential EV charging by mainstream consumers in Australia may be helpful. This is because even though residences seem to be the preferred charging location of the majorities, this group is probably underestimating their ability to charge at home. Consumer uncertainty about residential charging capability may delay adoption and create unfounded expectations about other charging options, such as the needed prevalence of public fast chargers. Since mainstream consumers do not seem to be convinced about both financial and environmental benefits of controlled charging, campaigns that explain the requirements, procedures and options for residential charging should also aim to educate consumers about controlled charging benefits.

Thirdly, our results indicate that workplace charging (and charging in car parks heavily used by commuters) can play an important role in demand management, especially if leveraging the use of solar energy. This is because commuters of all consumer groups show significant interest in workplace charging if it brings monetary savings. Since most vehicles are parked at workplace locations during the day, strategic deployment of PV charging infrastructure would enable consumers to charge for free (or for a minor fee) reducing residential charging during the evening.

Fourthly, pricing strategies, such as ToU tariffs, that reward off-peak charging with significant monetary savings (at least 50%) have the potential to attract between 50% and 80% of the consumers. However, as EV penetration increases, static ToU tariffs are likely to create new peaks, which may require more dynamic pricing mechanisms. In this scenario, consumers are more likely to be responsive and sustain an off-peak charging behaviour if the financial gains are clear and transparent, e.g. if they can monitor savings per charge or per day in a user-friendly application. If direct load control by suppliers becomes necessary, service design (i.e. utility plans) and user interface (i.e. smartphone applications) will need to focus on increasing user sense of control over charging while also facilitating their monitoring of monetary savings.

Finally, our literature survey points to the need for further investigation on the adoption and use of special tariff structures (ToU, tiered or EV specific) with or without the assistance of smart technologies by EV owners and future adopters. Countries like Australia that have an expressive potential for solar energy generation (already reflected in significant adoption of residential PVs) should use our results as a first step to further explore tariffs, service models, infrastructure deployment and smart management approaches that maximize mid-day charging.

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Conflicts of Interest

Both authors declared that they have no conflicts of interest. The agencies that provided funding for this research project are disclosed in the acknowledgments and they had no participation in the study design.

Authors' contributions

P.S.L.: conceptualization, formal analysis, investigation, methodology, project administration, validation, writing (original draft), review and editing. G.J.M.d.O.: data curation, formal analysis, visualization, writing (review and editing).

Data Availability

The data underlying this article cannot be shared publicly due to participant privacy reasons. The data collection was performed under the requirements of the Australian National Statement on Ethical Conduct in Human Research and approved by the Office of Research Ethics and Integrity of The University of Melbourne (ref. number 2021-20391-22 481-6). The approval constrained the data access to research team members specified in the application.

References

1. Ausgrid. *NSW Electric Vehicle Owners Survey: Summary Report*. 2020. https://www.ausgrid.com.au/-/media/Documents/Demand-Mgmt/DMIA-research/EV-Owners-Survey-Summary-Report.pdf?la=en&hash=0C623383DFD414A006C05C1FE685D1C1B213FAD3 (30 March 2022, date last accessed)
2. Australian Bureau of Statistics. *Motor Vehicle Census, Australia*. 2021a. https://www.abs.gov.au/statistics/industry/tourism-and-transport/motor-vehicle-census-australia/latest-release (30 March 2022, date last accessed)
3. Australian Bureau of Statistics. *Census of Population and Housing* 2016. 2021b. https://www.abs.gov.au/census (16 August 2021, date last accessed)
4. Australian Bureau of Statistics. *Household Income and Wealth, Australia*. 2022. https://www.abs.gov.au/statistics/economy/finance/household-income-and-wealth-australia (7 November 2022, date last accessed)
5. Australian PV Institute. *Mapping Australian Photovoltaic Installations*. 2021. https://pv-map.apvi.org.au/historical (16 August 2021, date last accessed)
6. Axsen J, Goldberg S, Bailey J. How might potential future plug-in electric vehicle buyers differ from current "Pioneer" owners? *Transp Res Part D: Transp Environ* 2016;**47**:357–70
7. Axsen J, Kurani KS. Who can recharge a plug-in electric vehicle at home? *Transp Res Part D: Transp Environ* 2012;**17**:349–53
8. Bailey J, Axsen J. Anticipating PEV buyers' acceptance of utility controlled charging. *Transp Res A Policy Pract* 2015;**82**:29–46
9. Carley S, Krause RM, Lane BW *et al.* Intent to purchase a plug-in electric vehicle: a survey of early impressions in large US cites. *Transp Res Part D: Transp Environ* 2013;**18**:39–45
10. Carloop. *Tesla Ownership Demographics*. 2022. https://carloop.com.au/carloop-tesla-ownership-data-trends/ (30 March 2022, date last accessed)
11. Corby S Plug-in hybrids explained: everything you need to know about PHEVs in Australia. In: *CarsGuide: Reviews, News and Advice*, 2022, https://www.carsguide.com.au/ev/advice/plug-in-hybrids-explained-everything-you-need-to-know-about-phevs-in-australia-84318#:~:text=A%20fully%20charged%20battery%20in,about%2036.4km%20per%20day (7 November 2022, date last accessed)
12. Delmonte E, Kinnear N, Jenkins B *et al.* What do consumers think of smart charging? Perceptions among actual and potential plug-in electric vehicle adopters in the United Kingdom. *Energy Res Soc Sci* 2020;**60**:101318
13. Haghani M, Bliemer MC, Rose JM *et al.* Hypothetical bias in stated choice experiments: part II. Conceptualisation of external validity, sources and explanations of bias and effectiveness of mitigation methods. *J Choice Model* 2021;**41**:100322
14. Hall S, Anable J, Hardy J *et al.* Matching consumer segments to innovative utility business models. *Nat Energy* 2021;**6**:349–61
15. Hardman S, Jenn A, Tal G *et al.* A review of consumer preferences of and interactions with electric vehicle charging infrastructure. *Transp Res Part D: Transp Environ* 2018;**62**:508–23
16. Higueras-Castillo E, Molinillo S, Coca-Stefaniak JA *et al.* Potential early adopters of hybrid and electric vehicles in Spain—towards a customer profile. *Sustainability* 2020;**12**:4345
17. IEA. *Global EV Outlook 2021, IEA, Paris*. 2021a. https://www.iea.org/reports/global-ev-outlook-2021 (30 March 2022, date last accessed)
18. IEA. *Global EV data explorer, IEA, Paris*. 2021b. https://www.iea.org/articles/global-ev-data-explorer (30 March 2022, date last accessed)
19. Kalton G, Flores-Cervantes I. Weighting methods. *J Off Stat* 2003;**19**:100322
20. Khoo YB, Wang CH, Paevere P *et al.* Statistical modeling of electric vehicle electricity consumption in the Victorian EV trial, Australia. *Transp Res Part D: Transp Environ* 2014;**32**:263–77
21. Kyriakidis M, Happee R, de Winter JC. Public opinion on automated driving: results of an international questionnaire among 5000 respondents. *Transport Res F: Traffic Psychol Behav* 2015;**32**:127–40
22. Lavieri PS, Bas Domenech C. Electric vehicle uptake and charging: a consumer-focused review. The University of Melbourne Technical Report, 2021. https://www.researchgate.net/profile/Patricia-Lavieri/publication/351355573_Electric_Vehicle_Uptake_and_Charging_A_Consumer-Focused_Review/links/609371b9458515d315fc1db3/Electric-Vehicle-Uptake-and-Charging-A-Consumer-Focused-Review.pdf (30 March 2022, date last accessed)
23. Lee JH, Hardman SJ, Tal G. Who is buying electric vehicles in California? Characterising early adopter heterogeneity and forecasting market diffusion. *Energy Res Soc Sci* 2019;**55**:218–26
24. Morrissey P, Weldon P, O'Mahony M. Future standard and fast charging infrastructure planning: an analysis of electric vehicle charging behaviour. *Energy Policy* 2016;**89**:257–70
25. Nicolson M, Huebner G, Shipworth D. Are consumers willing to switch to smart time of use electricity tariffs? The importance of loss-aversion and electric vehicle ownership. *Energy Res Soc Sci* 2017;**23**:82–96
26. Peters A, Dütschke E. How do consumers perceive electric vehicles? A comparison of German consumer groups. *J Environ Policy Planning* 2014;**16**:359–77
27. Priessner A, Sposato R, Hampl N. Predictors of electric vehicle adoption: an analysis of potential electric vehicle drivers in Austria. *Energy Policy* 2018;**122**:701–14

28. Rezvani Z, Jansson J, Bodin J. Advances in consumer electric vehicle adoption research: a review and research agenda. *Transp Res Part D: Transp Environ* 2015;**34**:122–36
29. Rogers EM *Diffusion of Innovations*, 5th edn. New York: Free Press, 2003
30. Sovacool BK, Axsen J, Kempton W. The future promise of vehicle-to-grid (V2G) integration: a sociotechnical review and research agenda. *Annu Rev Environ Resour* 2017;**42**: 377–406
31. Sovacool BK, Kester J, Noel L *et al.* The demographics of decarbonizing transport: the influence of gender, education, occupation, age, and household size on electric mobility preferences in the Nordic region. *Glob Environ Chang* 2018;**52**: 86–100
32. Tal G, Raghavan SS, Karanam VC *et al.* Advanced plug-in electric vehicle travel and charging behavior final report. *California Air Resour Board Contract* 2020;12–319
33. Vassileva I, Campillo J. Adoption barriers for electric vehicles: experiences from early adopters in Sweden. *Energy* 2017;**120**: 632–41
34. Will C, Schuller A. Understanding user acceptance factors of electric vehicle smart charging. *Trans Res Part C Emerg Technol* 2016;**71**:198–214
35. Wolff S, Madlener R. Charged up? Preferences for electric vehicle charging and implications for charging infrastructure planning. In: *Local Energy, Global Markets, 42nd IAEE International Conference, May 29–June 1, 2019*. International Association for Energy Economics, 2019
36. Wong SD, Shaheen SA, Martin E *et al. Do Incentives Make a Difference? Understanding Smart Charging Program Adoption for Electric Vehicles*. Berkeley: Institute of Transportation Studies, 2022
37. Zarazua de Rubens G. Who will buy electric vehicles after early adopters? Using machine learning to identify the electric vehicle mainstream market. *Energy* 2019;**172**: 243–54