Applying a latent class cluster analysis to identify consumer segments of electric vehicle charging styles

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SHORT SUMMARY

Electric vehicle market growth makes understanding user charging behaviour essential for policy design and EV adoption facilitation. In this study, we examined the heterogeneity in charging preferences of 994 respondents across Australia, using a latent class cluster model that considers indicators of charging behaviour as outcomes of interest. We used sociodemographic characteristics, travel needs, and EV adoption status as covariates to predict class membership. Our findings identify five segments of consumers with distinct charging style preferences: cost-sensitive planners, cost-sensitive on-demanders, predictability seekers, flexibility seekers, and indifferent late adopters. We provide targeted policies for each segment based on their charging style and profile, aimed at facilitating EV adoption and meeting their charging needs. Our results suggest that two broad categories of action are necessary to facilitate EV adoption and meet charging needs of upcoming EV users: improving EV-related knowledge and providing economical home charging options.

Keywords: Charging style, electrification and decarbonization of transport, latent class cluster analysis

1. INTRODUCTION

Transitioning to Electric Vehicles (EVs) from Internal Combustion Engine Vehicles (ICEVs) requires significant behavioural changes and increased cognitive effort from consumers, as charging decisions are multidimensional, involving scheduling, location and charger type choice, and highly variable prices. While current activity-based demand models tend to assume that drivers deliberate about charging before or after every trip based on the battery state of charge and charger availability, this assumption may not be behaviourally realistic for many EV users. That is, users may reduce the cognitive load of charging decisions by using heuristics, relying on daily routine cues and habit. In this sense, segmenting individuals based on their behavioural patterns can be a more effective way of modelling charging behaviour.

The notion of “style”, as in “lifestyle” (Talvitie, 1997), "mobility style" (Lanzendorf, 2002), "modality style" (Vij et al., 2013), has been adopted by researchers to represent behavioural patterns together with their underlying motivations and attitudes towards different aspects of life, travel, and/or modal preferences. Analogously, the term “charging style” can be used to represent charging behaviour patterns (including heuristics and cues that individuals may use) associated with underlying personal subjective orientations. Yet, only a couple of studies have explored this idea.

Franke et al. (2013) proposed that EV users adopt a charging style as a preferred coping strategy to interact with the limited battery resources of their vehicles. They developed the concept of user battery interaction style (UBIS) to measure differences in coping strategies related to charging. An individual with high UBIS makes charging decisions based on the vehicle's state of charge, while people with low UBIS use other cues to make a charging decision, such as routine or opportunity. Subsequently, Daina et al. (2015) used this concept of UBIS to predict charging demand. Although UBIS can capture the coping strategies of EV users, it does not define charging style as a representation of a general pattern of charging. That is, it requires additional factors to generate a prediction of charging choices.

Considering that a comprehensive construct representing charging styles can benefit integrated energy and transport demand models, the current study utilises empirical data from a survey with EV owners and potential owners together with a latent class cluster analysis (LCCA) approach to (1) identify classes of electric vehicle charging styles, (2) define user profiles for each style, and (3) provide tailored policy recommendations to facilitate charging and potentially increase EV adoption among consumers with different styles.

2. METHODOLOGY

The conceptual framework of this study, as shown in Figure 1, aims to classify current and prospective EV users into different classes based on their charging style. The dimensions of charging style were identified based on literature review and include three main categories: charging attributes, coping strategy with battery resources, and risk attitude.

Charging attributes include three dimensions representing user preferences regarding charging: (1) time regularity, (2) location, (3) trade-offs between cost and charging speed, and cost and perceived convenience. To measure individuals' coping styles related to charging, a scale was developed based on UBIS, measuring the trade-off between battery level and opportunity, and battery level and routine. Risk attitude was not directly considered, but it was inferred through the trade-off between planning for charging and deciding on the go. The framework also takes into account socio-demographic characteristics, EV adoption cohort, and travel needs to understand the charging profile of people in different classes.

2.1 Latent class cluster analysis

LCCA is used to reveal the charging style classes using poLCA package (Linzer and Lewis, 2011). LCCA groups individuals into distinct charging style classes based on observable charging preferences and individual characteristics. The model has a measurement component, which links the underlying latent categorical variable to its indicators, and a structural component, which defines the relationships between explanatory covariates (active covariates) to determine class membership. The model simultaneously estimates these sub-models using a probabilistic approach. Inactive covariates provide additional profiling of the identified classes.

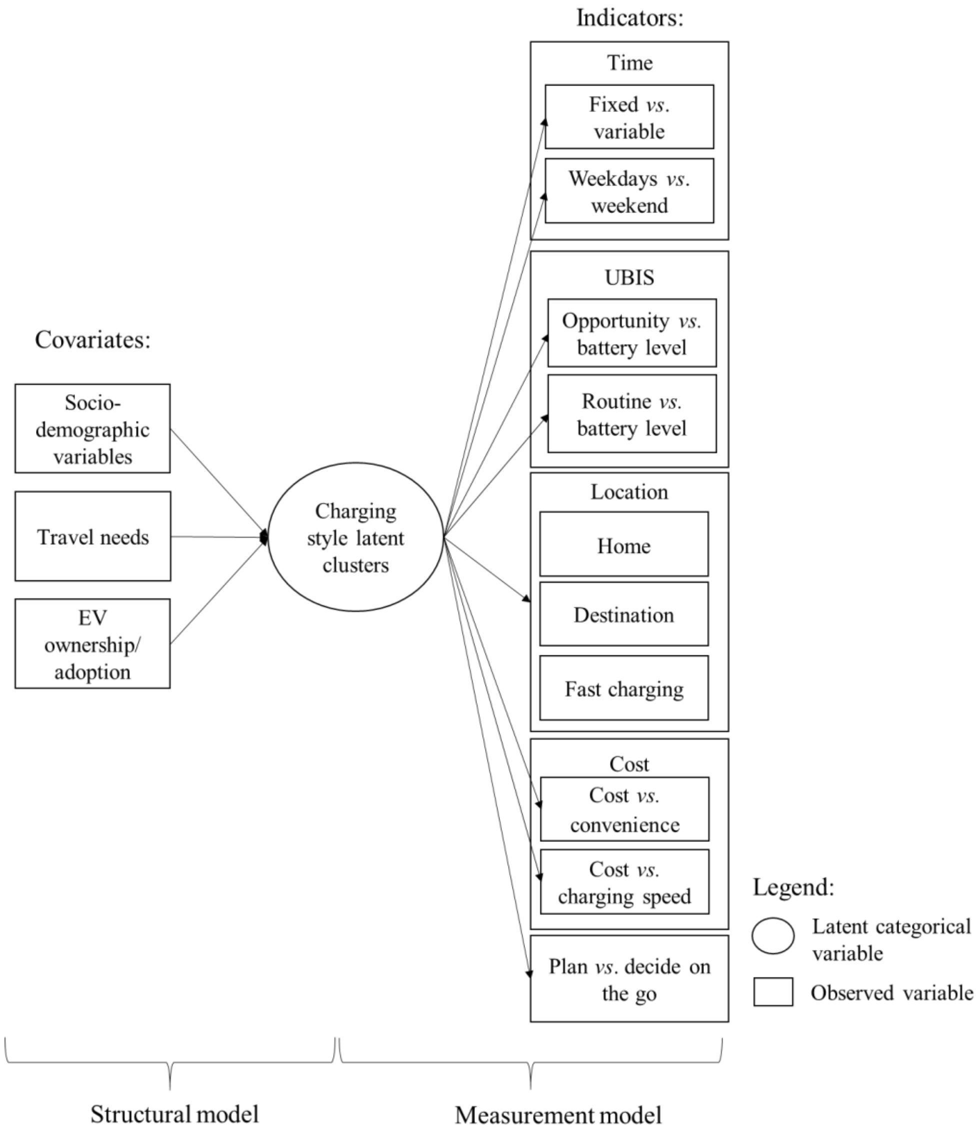

Figure 1: Conceptual Framework

2.2 Data collection and sample

We obtained our data through an online survey conducted between July and August of 2021 as part of the EV Integration (2020-2022) project in Australia (University of Melbourne, 2022). The sampling strategy aimed for around 10% responses from EV drivers and a sample of ICEV drivers representative of the Australian driver population. The final sample size comprised 994 observations, including 97 EV drivers. The survey collected information on socio-demographic characteristics, travel needs, EV ownership and intentions to purchase, and charging preferences. We used three cohorts of EV adoption: EV owners, early majorities (likely to own an EV within five years), and late majorities (likely to own an EV within ten years or have no plans to own one). Detailed information about the data can be found in the project's report (Lavieri and Oliveira, 2021).

The last column of Table 2 shows descriptive statistics of the sample. While the sample is not representative of the overall driving-age population due to the oversampling of EV owners, the sub-sample of ICEV drivers is. Relative to the driving-age population, EV owners in the sample are more likely to be men, in 35-54 age category, have tertiary education, be employed full-time, and have high income. Furthermore, they drive twice the national average of annual distances driven per person.

3. RESULTS AND DISCUSSION

Models with 2 to 6 classes were compared using AIC and BIC, and the five-class model was chosen as the best fit. Tables 1 and 2 present the behaviour and the profile of each class while Table 3 presents the class membership model results.

3.1 Charging styles and profiles

Class 1: 26.7% of the total sample are cost-sensitive planners who prefer home charging and prioritize cost over convenience or speed. This group mostly charges based on routine and opportunity. They usually charge on weekdays and plan their charging in advance. This class has the highest proportion of mid-low-income households, the largest share of households with solar panels, and high vehicle ownership.

Class 2: Comprising 27.5% of the total sample, cost-sensitive "on-demanders" prefer home charging, prioritize cost over convenience, and charge based on battery level. This class has a high proportion of homeowners, households with off-street parking, and late majorities (in terms of EV adoption).

Class 3: Named as predictability seekers, they make up 18.9% of the total sample and prioritize convenience over cost. They tend to charge their vehicles based on routine and opportunity. They prefer home charging. They have the highest average weekly distance travelled and plan their charging in advance to meet their travel needs. This class has the highest proportion of high-income households, women, and those in early majority cohort.

Class 4: Flexibility seekers comprise 18.5% of the total sample and prioritize charging convenience and speed over cost. They charge based on battery level. This group prefers fast charging and destination charging the most among the five classes. This class has the highest proportion of men, young individuals, high-income earners, highly educated individuals, and EV owners.

Class 5: known as Indifferent Late Adopters, they make up 8.5% of the sample. They have no defined charging preferences yet. This group has the highest proportion of individuals who are unemployed or not in the workforce, low-income households without solar panels and/or off-street parking, or individuals living in rented properties. They are mostly among the late adopter cohort.

Table 1: Summary Statistics of Indicators

	Class 1	Class 2	Class 3	Class 4	Class 5	Sample total
Class name	*Cost-sensitive planners*	*Cost-sensitive "on-demanders"*	*Predictability seekers*	*Flexibility seekers*	*Indifferent late adopters*	
Class share (%)	26.7	27.5	18.9	18.5	8.5	100
Class size (n)	271	274	185	179	85	994
Opportunity vs. battery level:						
Opportunity	**80.2%**	17.9%	43.1%	30.1%	2.2%	40.2%
Equal	13.9%	46.0%	32.6%	17.0%	**94.6**%	33.6%
Battery level	5.9%	36.1%	24.4%	**52.9**%	3.3%	26.2%
Routine vs. battery level:						
Routine	**96.1%**	32.0%	57.9%	18.6%	0.0%	48.9%
Equal	2.8%	29.4%	17.0%	10.1%	**95.6**%	21.9%
Battery level	1.1%	38.6%	25.1%	**71.4**%	4.4%	29.2%
Charging location preference:						
Home	70.7%	**79.0**%	74.0%	51.1%	57.8%	68.9%
Destination charging	10.9%	8.2%	9.1%	**17.9**%	16.2%	11.6%
Fast charging	18.3%	12.8%	16.9%	**31.0**%	26.0%	19.5%
Cost vs. convenience:						
Cheapest	**90.4%**	83.6%	2.4%	8.0%	0.0%	49.1%
Equal	1.7%	10.0%	54.4%	7.4%	**89.0%**	22.3%
Most convenience	7.9%	6.4%	43.2%	**84.6%**	11.0%	28.6%
Cost vs. charging speed:						
Cheapest	95.3%	**97.5%**	19.7%	11.6%	0.5%	58.1%
Equal	2.9%	2.5%	61.9%	12.4%	**92.4%**	23.2%
Fastest	1.8%	0.0%	18.4%	**76.1%**	7.1%	18.6%
Day:						
Weekdays	**84.2%**	26.7%	63.4%	36.1%	2.2%	48.7%
Equal	9.5%	50.7%	28.6%	20.6%	**94.4%**	33.6%
Weekends	6.3%	22.7%	8.0%	**43.3%**	3.4%	17.7%
Time of day:						
Same	**91.1%**	38.2%	58.7%	37.1%	0.0%	52.8%
Equal	6.6%	41.8%	25.0%	22.0%	**99.3**%	30.4%
Different	2.3%	20.1%	16.3%	**40.9**%	0.7%	16.8%
Plan vs. decide on the go:						
Plan	**85.8%**	61.5%	51.3%	36.8%	0.0%	56.3%
Equal	10.0%	34.3%	35.2%	15.8%	**98.7%**	30.0%
Decide on the go	4.2%	4.2%	13.4%	**47.4%**	1.3%	13.7%

Table 2: Summary Statistics of Covariates

Covariates	Class 1	Class 2	Class 3	Class 4	Class 5	Sample total
EV ownership and adoption status:						
Early majority	39.9%	35.5%	**40.6%**	31.8%	33.6%	36.8%
EV owners	4.2%	1.9%	12.9%	**29.3%**	3.5%	9.8%
Late majority	55.9%	62.6%	46.6%	38.9%	**62.9%**	53.4%
Gender:						
Female	52.9%	43.4%	**55.5%**	32.1%	49.7%	46.7%
Male	47.1%	56.6%	44.5%	**67.9%**	50.3%	53.3%
Age:						
18 to 34	29.7%	20.0%	23.1%	**36.3%**	33.7%	27.4%
35 to 54	33.8%	35.7%	38.5%	**42.1%**	27.5%	36.2%
55 and older	36.5%	**44.3%**	38.4%	21.6%	38.8%	36.4%
Income:						
$100,000 or more	41.0%	43.9%	52.5%	**73.4%**	46.3%	50.4%
$35,000 to $99,999	**42.2%**	41.6%	31.4%	14.1%	36.1%	34.3%
Less than $34,999	16.8%	14.5%	16.1%	12.5%	**17.6%**	15.3%
Education: *<Inactive>*						
Bachelor and higher	35.8%	40.6%	37.9%	**59.1%**	38.5%	42.1%
Below bachelor	**64.2%**	59.4%	62.1%	40.6%	61.5%	57.9%
Employment status: *<Inactive>*						
Full-time	40.2%	36.0%	44.0%	**65.4%**	43.3%	44.7%
Not in workforce or unemployed	35.3%	41.0%	34.8%	25.9%	**42.3%**	35.6%
Part time	**24.5%**	23.1%	21.3%	8.7%	14.4%	19.7%
Family composition:						
Have children	43.4%	32.3%	27.3%	**52.8%**	30.15	37.9%
No children	56.6%	67.7%	**72.7%**	47.2%	69.9%	62.1%
Average number of cars in household	**1.81**	1.78	1.77	1.54	1.43	1.71
Living situation: *<Inactive>*						
Own	67.4%	**74.6%**	74.1%	72.8%	65.0%	71.4%
Rent	32.6%	25.4%	25.9%	27.2%	**35.0%**	28.6%
Building type: *<Inactive>*						
Flat or apartment	10.3%	7.2%	9.8%	**15.2%**	10.4%	10.3%
Separate house	69.7%	**76.5%**	66.1%	59.4%	74.7%	69.4%
Townhouse	9.8%	7.8%	12.8%	**17.2%**	8.4%	11.1%
Other	10.2%	8.5%	11.3%	8.2%	6.5%	9.2%
Having off-street parking:						
No	10.2%	7.1%	15.9%	17.3%	**23.9%**	12.9%
Yes	89.8%	**92.9%**	84.1%	82.7%	76.1%	87.1%
Having solar panels:						
No	63.1%	67.7%	64.8%	73%	**75%**	67.5%
yes	**36.9%**	32.3%	35.2%	27%	25%	32.5%
Average typical weekly distance travelled (km)	229.0	154.3	**246.8**	237.2	174.4	208.8
Average time window (hour)	25.0	28.3	25.5	23.8	**29.0**	26.1
Solar Panel condition: *<Inactive>*						
Do not have	40.6%	49.2%	47.4%	56.6%	**69.2%**	49.6%
Already have	**36.9%**	32.3%	35.2%	27.0%	25.0%	32.5%
Will adopt if buy an EV	**22.5%**	18.5%	17.4%	16.4%	5.8%	17.9%

3.2 Class membership model

The cost-sensitive planners serve as the reference category, and coefficients are interpreted accordingly. In summary, belonging to:

- Class 2 is more likely for individuals with high income and no children, but less likely for those who drive long distances.

- Class 3 is more likely for EV owners, those aged 35 or more, and those with income between $35,000 to $99,999 and no children. Less likely for those with off-street parking.
- Class 4 is more likely for EV owners, males, and those with income between $35,000 to $99,999 or $100,000+, but less likely for those with more cars or off-street parking and solar panels.
- Class 5 is more likely for those with income between $35,000 to $99,999 and less likely for those with more cars or off-street parking.

Table 3: Class Membership Model

Covariates	Class 2 vs. class 1	Class 3 vs. Class 1	Class 4 vs. Class 1	Class 5 vs. class 1
	Coef. (t-stat)	Coef. (t-stat)	Coef. (t-stat)	Coef. (t-stat)
Intercept	-0.690(-1.042)	-0.621(-0.903)	1.805(2.644)	1.343(1.815)
EV adoption status *(reference: early majority)*				
EV owners	-	1.174(2.320)	2.269(4.753)	-
Late majority	-	-	-	-
Gender *(reference: female)*				
Male	-	-	0.700(3.044)	-
Age *(reference: 18 to 34)*				
35 to 54	-	0.787(2.161)	-0.631(-1.800)	-
55 and older	-	0.819(2.343)	-	-
Income *(reference: Less than $34,999)*				
$35,000 to $99,999	-	0.626(2.132)	1.497(4.114)	0.623(1.960)
$100,000 or more	0.658(1.912)	-	0.784(1.685)	-
Family composition *(reference: have children)*				
Do not have children	0.532(2.134)	1.076(3.657)	-	-
Average number of cars in household	-	-	-0.407(-2.472)	-0.659(-2.592)
Having off-street parking *(reference: no)*				
Yes	-	-0.663(-1.835)	-0.706(-1.916)	-0.949(-2.317)
Having solar panel *(reference: no)*				
Yes	-	-	-0.763(-2.572)	-
Typical weekly distance (km)	-0.002(-3.265)	-	-0.001(-1.998)	-

3.3 Policy recommendation

Our study found that EV users may exhibit diverse charging behaviours, and therefore we discuss tailored policies that could be targeted at each charging style segment. We conducted a literature review of pertinent policies and identified three main categories of recommendations that could be customised to each class: 1) financial and regulatory support for residential charging, 2) financial and regulatory support for solar charging, and 3) educational campaigns.

Class 1:

1. Offer financial incentives to landlords for installing level 2 chargers or low-interest loans to tenants for home charger installation. Streamline permitting processes for installation in rental properties.
2. Offer tax credits or incentives for solar panel installation and promote shared solar programs. Offer bundled incentives for EV and solar purchases to encourage the adoption of both technologies.
3. Provide information about the financial incentives available for EV purchase and home and solar charging, along with the long-term cost savings associated with solar charging.

Class 2:

1. Offer cash rebates or discounts for EV adoption and home charger installation.
2. Offer tax credits and incentives for solar panel purchase and installation.
3. Offer educational campaigns that raise awareness about financial incentives for EV purchases, home charging, and solar charging.

Class 3:

1. Allocate curb-side or public charging options for those without access to off-street parking.
2. Offer EV and solar panel bundles, emphasizing their convenience and environmental benefits. Encourage community solar programs. solar panel installation, and flexible work policies.
3. Educate consumers on the increasing driving range of EVs and how home charging can adequately meet their travel needs. Highlight the expanding network of public chargers as a backup. Additionally, emphasize the long-term benefits associated with solar charging.

Class 4:

1. Facilitate approval for home charging installation and offer curb-side or public charging for those without access to off-street parking.
2. Programs that promote the adoption of solar batteries and encourage weekend charging, as well as support working from home to overcome the limited flexibility barrier for solar charging in this group.
3. Highlight the increasing driving range of EVs, educate consumers on the adequacy of home charging for their travel needs, and emphasize the growing network of public chargers as a backup.

Class 5:

Educational campaigns to increase the knowledge about EVs is a prerequisite for this class, which does not even consider EV adoption in a distant future. This can be achieved through EV festivals, test drives, and incentives, while also making them aware of available support for charging their EVs, including financial and regulatory assistance.

4. CONCLUSIONS

In this study, we performed a LCCA to identify five distinct charging style classes among current and prospective EV users in Australia. Indifferent late adopters have no preferred charging style, while flexibility seekers prioritize speed, convenience, and battery level. Predictability seekers have a fixed charging time and location preference. The largest classes, cost-sensitive planners and on-demanders, prioritize cost savings and home charging. Based on the likely behavioural pattern of each class, as EV adoption continues to grow, home charging will become increasingly crucial, and offering an affordable home charging option is key to meeting the needs of many upcoming EV adopters.

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