User preferences for future electric vehicle charging infrastructure: A Stated Choice Experiment for Danish EV users

Anant Atul Visaria[1], Anders Fjendbo Jensen[1], Mikkel Thorhauge[1]

[1] Department of Management Engineering, Technical University of Denmark

1 Introduction

While the adoption EVs is rapidly growing, the global EV stock is still less than 1% of car fleet. It is expected that in coming years, with improved technology, the battery size and in turn the EV driving range will increase. The fact that EV prices will reduce over time and many countries intend to set up policies to support the purchase and use of EVs, it is expected that the EV adoption rate will continue to increase. However, this also means that there's a need for better planning, especially for the charging infrastructure, to improve and support the transition to e-mobility.

There is a strong behavioral and social aspect associated with the use of electric vehicles. This study tries to develop a qualitative and quantitative understanding of the most relevant aspects. The findings presented in this paper focuses on understanding the preferences of Danish EV users. The aim is to identify key attributes that influence the decision making of EV users, especially when it comes to charging their cars. To do so, a literature review and qualitative interviews of EV users from across Denmark were conducted. Based on this, two stated choice experiments are developed to further investigate user preferences. The survey was shared with EV users across Denmark, and using the data collected, two discrete choice multinomial models are developed.

2 Survey Design

Based on the findings and qualitative assessment from literature review as well as the qualitative user interviews, it was identified that two main decision-making situations needs to be studied further to better understand the underlying user preferences; *Long term decisions*, like what kind of pricing plan or charging network membership they need to meet their regular charging demands and *instantaneous decisions* that take into consideration various aspects like cost and convenience to decide where they would like to charge, especially on longer trips. Therefore, the following two stated choice experiments are developed, to test preferences of Danish EV users.

6.1 Long Term Design Setup: user preferences for everyday charging

This is a labelled setup to identify what kind of pricing plans do EV users prefer.

The attributes considered are:

- Subscription cost
- Personal home charging cost
- Public charging cost
- Network access.

The four alternatives are:

No Contract: This plan is similar to what conventional car users have for gas. It does not have any monthly subscription cost. Just a different cost for home and public charging.

Flat fee: This plan has only a monthly subscription fee, with no additional cost for home or public charging.

Monthly Subscription 1: This plan has a monthly subscription fee, along with different pricing for home and public charging.

Monthly Subscription 2: This plan is similar to monthly subscription 1. However, public charging cost is time based. Here, peak hours are defined as are Monday to Friday 6am to 9am and 4pm to 7pm.

The setup considers combinations of following levels:

	No Contract	**Flat Fee**	**Monthly Subscription 1**	**Monthly Subscription 2**
Subscription Cost (kr.)	0	700/600/500	150/100/50	150/100/50
Home Charging Cost (kr./kWh)	1.5/2/2.5	0	1.5/2/2.5	1.5/2/2.5
Public Charging Cost (kr./kWh)	8/6/4	0	2.5/3.5/4.5	Peak hours: 3.5/4.5/5.5 Off-Peak hours: 2/3/4
Network Access	All networks in EU	One network in DK/ All networks in DK/ All networks in EU		

Table 1 Survey design for long term decisions

6.2 Instantaneous Design Setup: user preferences for occasional charging on long(er) trips

This is an unlabeled setup to identify the user preference for charging on long trips. The users need to assume that you are on a long trip and their EV battery is at 20% capacity. So, they need to charge at a public fast charger and are looking for options nearby.

Three unlabeled alternatives are considered, with the following attributes:

Detour (in minutes): This shows, how much time will be needed to get off the main road and get to the charging station.

Chargers available: This shows, how many charging spots are available out of the total number of charging spots at the location. For e.g. 2 out of 4 means, 2 charging spots are vacant at the given moment, out of the 4 spots at this location.

Charging Speed (in km per 10 minutes of charge): This shows, estimated range added (in km) after 10 minutes of charging. The values are applicable for charging upto 80 to 85% of battery capacity.

Cost (in DKK/kWh): This shows, how much you need to pay per unit of power (i.e. per kWh). Remember this is not based on your choices in the previous scenario and consider that you have no prior subscription plan with the charging network.

Additional Facilities: This shows, what additional amenities are available at the charging location.

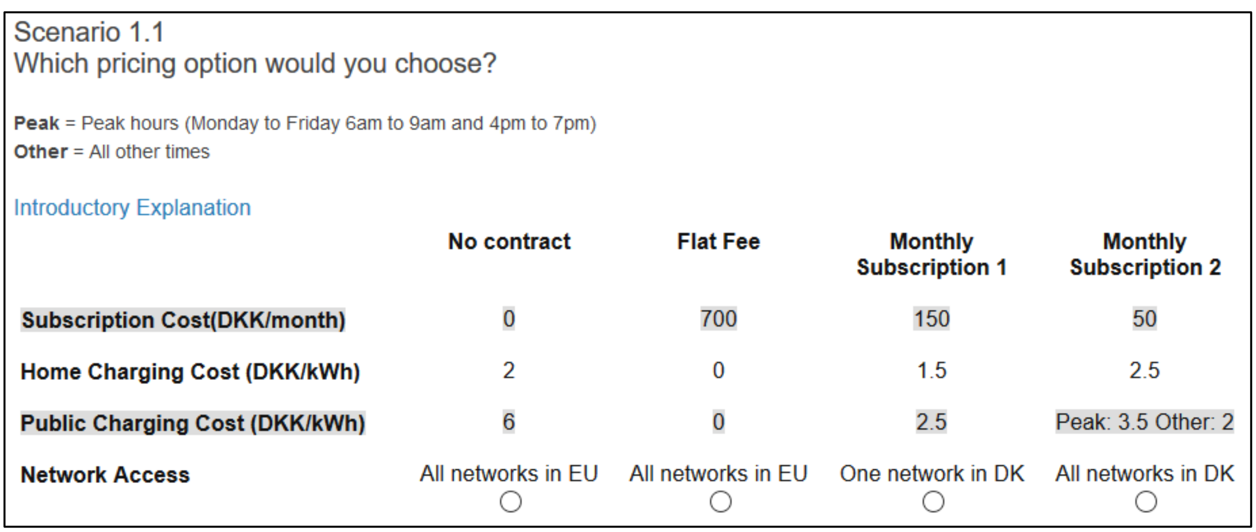
The levels corresponding to the attributes are shown in the table below:

Attributes	**Levels**
Detour (minutes)	0/5/10
Chargers Available	0/1/2 out of 1/4/10
Charging speed (km/10 min.)	60/85/110
Cost (kr./kWh)	4/6/8
Additional Facilities	None/ Only Restroom/ Restroom, Supermarket and Restaurants

Table 2 Attributes and corresponding levels for Instantaneous Decision survey design

3 Final Survey

Each survey was orthogonally designed to have twenty-seven choice scenarios, divided in nine blocks. The survey was released in March 2019, and 558 Danish EV users answered the complete survey. Each user was presented with three choice scenarios for each survey design. The final survey can be seen in the following images:



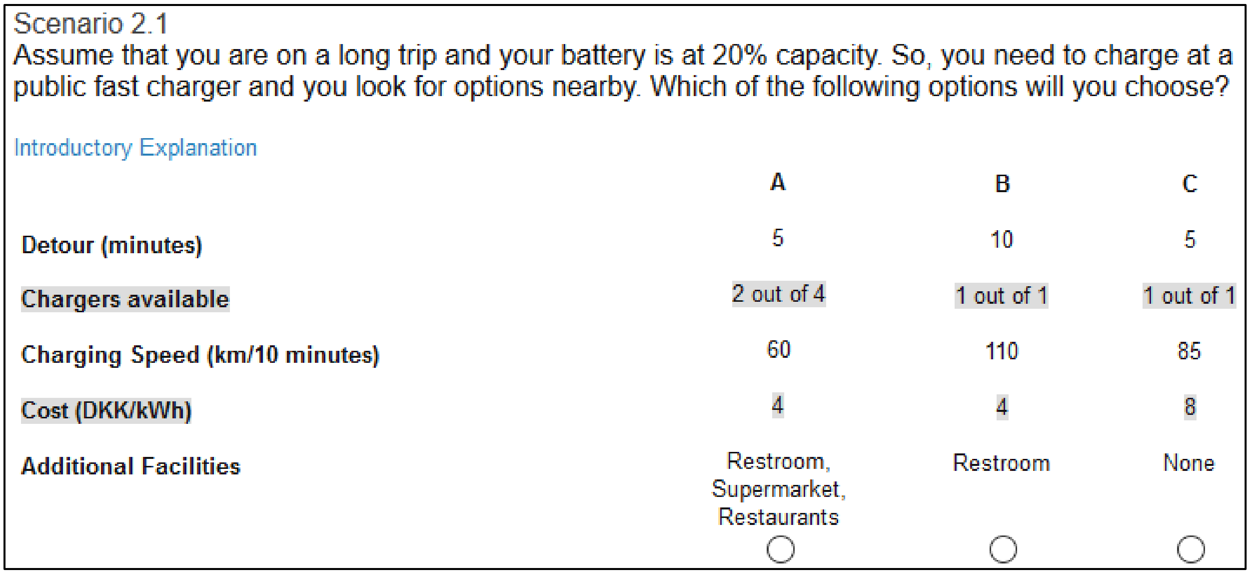
Scenario 1.1
Which pricing option would you choose?

Peak = Peak hours (Monday to Friday 6am to 9am and 4pm to 7pm)
Other = All other times

Introductory Explanation

	No contract	**Flat Fee**	**Monthly Subscription 1**	**Monthly Subscription 2**
Subscription Cost(DKK/month)	0	700	150	50
Home Charging Cost (DKK/kWh)	2	0	1.5	2.5
Public Charging Cost (DKK/kWh)	6	0	2.5	Peak: 3.5 Other: 2
Network Access	All networks in EU	All networks in EU	One network in DK	All networks in DK

Figure 1 Stated Preference 1: Long Term Decision about Pricing Structure



Scenario 2.1
Assume that you are on a long trip and your battery is at 20% capacity. So, you need to charge at a public fast charger and you look for options nearby. Which of the following options will you choose?

Introductory Explanation

	A	B	C
Detour (minutes)	5	10	5
Chargers available	2 out of 4	1 out of 1	1 out of 1
Charging Speed (km/10 minutes)	60	110	85
Cost (DKK/kWh)	4	4	8
Additional Facilities	Restroom, Supermarket, Restaurants	Restroom	None

Figure 2 Stated Preference 2: Instantaneous Decision about Charging Location

4 Modeling Results

In total 558 respondents completed the survey. Based on the data collected a two multinomial logit model was developed to identify significant attributes.

4.1 MNL model for Long Term Pricing Preferences

Out of a total 1674 observations, the Flat Fee alternative was chosen in 54%, No Contract in 23%, Monthly Subscription 1 in 13% and Monthly Subscription 2 in 10%. Based on these preferences the following estimates were obtained.

Name	Description	Value	t-test
B_subFF	Subscription Cost (Flat Fee)	-0.0022	-4.96
B_subMS	Subscription Cost (Monthly Subscription 1 and 2)	-0.00757	-5.51
B_home	Home charging cost	-0.177	-3
B_pub	Public charging cost	-0.161	-4.95
B_network2	Network access to All Networks in DK	0.139	1.49
B_network3	Network access to All Networks in EU	0.276	2.96
B_TeslaFF	Tesla User (included only for Flat Fee)	1.29	11.2
ASC_FF	ASC for Flat Fee	0.932	2.71
ASC_MS1	ASC for Monthly Subscription 1	0.169	1.55
ASC_NC	ASC for No Contract	0.572	3.29

Table 3 MNL results for Long Term Pricing Preferences

Based on the results it can be seen that all attributes from the long-term pricing preferences have the expected sign and all are significant at 99% confidence, except one of the network attributes which is significant at ~50% confidence. Specifically, the cost parameters for subscription cost, home charging cost and public charging cost are negative and statistically significant. This implies that, as expected, the utility of an alternative would reduce if costs were increased. Moreover, utility increases when the pricing structure offers network access to all networks in EU. Additionally, it is seen that if the user is a Tesla user, then he/she finds a greater utility from Flat Fee option. This could probably be due to their preference for convenience.

4.1 MNL model for Instantaneous Charging Location Preferences

The second survey design was an unlabeled, and also has 1674 observations, for which the results obtained from the MNL model are as seen in the table below.

Name	Description	Value	t-test
B_detour	Detour	-0.0831	-8.63
B_available	Chargers vacant	0.546	12.6
B_total	Total chargers at location	0.0225	1.66
B_speed	Charging Speed	0.01	4.42
B_cost	Cost for charging	-0.394	-17.1
B_fac2	Only Restroom Available	0.127	1.61
B_fac3	Restroom, Supermarket, Restaurants available	0.648	7.13
B_SpeedTesla	Charging speed, preference Tesla users	0.02	6.18
B_TotalTesla	Total chargers available, preference Tesla users	0.0374	1.9

Table 4 MNL results for Instantaneous Charging Location Preferences

The results show that an increased detour, and increased cost, would have a negative effect on the utility derived for a charging location, based on the statistical significance of relevant parameters. Moreover, increased availability of vacant chargers, and increased charging speed, both have a positive effect on the utility. Additionally, it can be seen that additional facilities like restroom, supermarket and restaurant make charging locations preferable as well. Lastly, it is also observed that Tesla users have a significant desirability for higher charging speeds and more total number of chargers at a location.

While, the results are rather preliminary, these findings have great implications for the planning and development of future EV charging infrastructure in Denmark. The findings from the long term scenarios points to a need for a convenient and simplified method of pricing of EV charging, and also the lowering of costs. The instantaneous scenarios show how the charging locations can be made more convenient for the users, and what technical preferences they have. All in all this study shows how EV infrastructure can be improved to increase EV adoption, in order to compete with existing conventional car usage. Further improvements of the models involves accounting for systematic heterogeneity in preferences and estimating of mixed logit model to account for panel effect.