Preferences For Electric Vehicle Charging

A Latent Class Approach

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FCN | Future Energy Consumer Needs and Behavior

E.ON Energy Research Center

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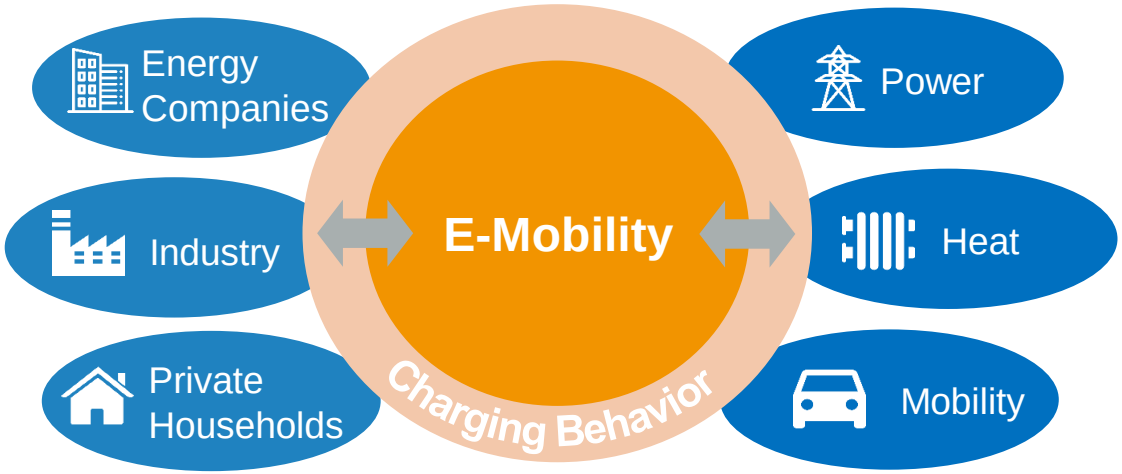
1. Motivation
E-Mobility as a focal point between energy and mobility transitions



Energy transition

- Reduce fossil fuel dependency and CO_2 emissions
- Smart home integration

Charging behavior

- Charging preferences of (future) consumer groups

Mobility transition

- Electric mobility driving and charging behavior

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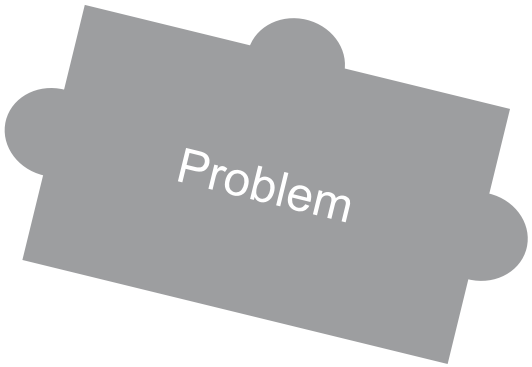
1. Motivation
Research Gap



EV charging infrastructure investments are high & income streams are low (Ito et al. 2013)

- Who is responsible? Car manufacturers, state, municipalities, energy companies? → Business case still missing

Offering charging solutions

- Necessary to understand preferences of current and potential future EV drivers

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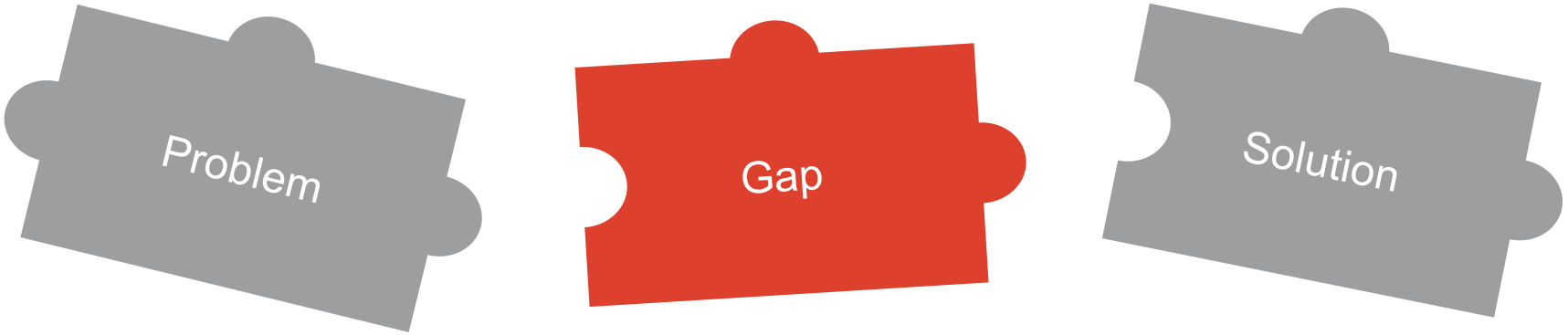

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Some literature on single attributes of the charging process

- Assessment of EV drivers' willingness to pay for different attributes of charging process (charging speed, location, and price; Hackbarth & Madlener 2013, 2016; Hidrue et al. 2011; Tanaka et al. 2014)

Gap

- Charging behavior as a whole bundle including related services

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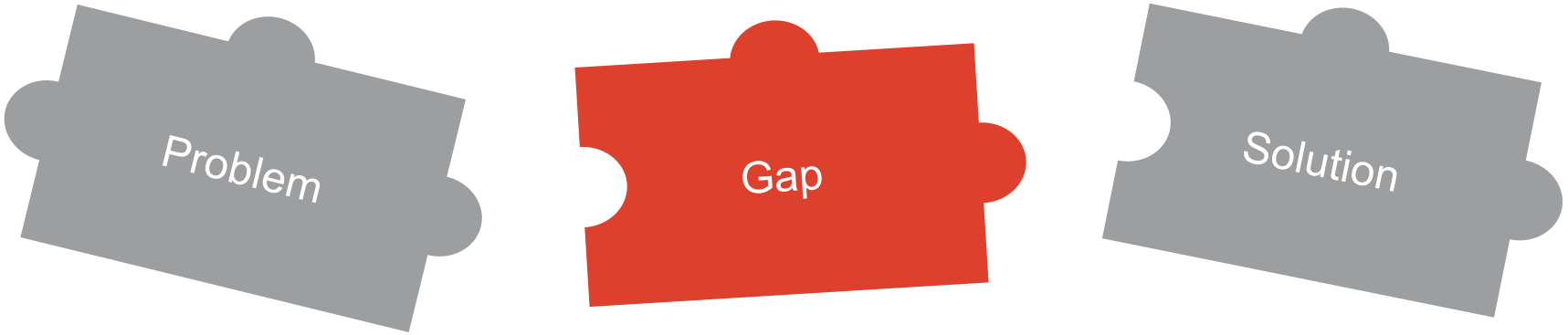

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What kind of charging behavior is to be expected in a more mature EV market?

- Sample size too small for field experiment → online experiment

Discrete choice experiment

- Measuring preferences for attributes indirectly by confronting respondents with hypothetical choice bundles
- Targeting potential EV customers

Introduction to respondents

“Assume that you regularly drive and charge an e-car. The range of the e-car is sufficient for your daily driving needs. Please imagine how and where you would like to charge the e-car’s battery. Please assume that the two options are identical in all aspects not mentioned here, i.e. assume a generic e-car that is identical with respect to size, range, motor power etc.“

Example of a Choice Card (full range of attributes). Repeated 12 times for each respondent.

ATTRIBUTES	LEVELS	
Place of charging	At home	At work
Charging duration (full charge)	10 min	4 hours
Charging technology	Tethered charging (with cable)	Inductive charging (without cable)
Waiting time for available charging station	0 min	30 min
Share of renewables	50 %	25 %
Charging cost per month	200 €	100 €
	○ **OPTION A**	○ **OPTION B**

CHOICE

2. Methodology
Discrete Choice Experiment

- The number of both attributes and levels is limited so that respondents are not overburdened
- The design algorithm ensures that all levels appear on the same number of choice cards
- Individuals maximize their utility by choosing a particular charging solution
- Respondents are forced to consider tradeoffs between the attributes that define the two options A and B

Overview of Attribute Levels				
Place of charging	At home	At work	Roadside: Primary	Roadside: Secondary
Charging duration (full charge)	10 min	30 min	4 hours	8 hours
Charging technology	Tethered charging (with cable)		Inductive charging (without cable)	
Waiting time for available charging station	0 min	5 min	10 min	30 min
Share of renewables	25 %	50 %	75 %	100 %
Charging cost per month	50 €	100 €	150 €	200 €

ATTRIBUTES

LEVELS

4. Latent Class Model Methodology

- Multinomial Logit (MNL)
  - Individuals maximize their utility by choosing a particular charging solution
  - Homogeneous preferences, i.e. one coefficient for each attribute level

$$W_{in} = \beta_i + \beta_A A_i$$

- Latent Class Models (LCM)
  - Assumes the existence of classes within the population that are unobservable for the researcher
  - Preferences differ between classes, but are homogeneous within groups
  - One coefficient **per class** for each attribute level

$$W_{inc} = \beta_{ic} + \beta_{Ac} A_i$$

W = observed utility

i = option (A or B)

β = coefficients

A = attributes

c = class

4. Latent Class Model
Estimation Results 1/3

	MNL	Latent Class Model					
Parameters		**Class 1**	**Class 2**	**Class 3**	**Class 4**	**Class 5**	**Class 6**
Costs: 50 €	(base)	(base)	(base)	(base)	(base)	(base)	(base)
Costs: 100 €	-0.61***	-0.77***	-2.32***	-0.76***	-0.61***	0.04	-0.45***
Costs: 150 €	-1.22***	-1.39***	-4.39***	-1.60***	-1.19***	-0.11**	-0.82***
Costs: 200 €	-1.91***	-2.19***	-7.01***	-2.47***	-2.07***	-0.20***	-1.46***
N	4,097	812	1,280	775	291	693	246

* p <0.1, ** p <0.05, *** p < 0.01

- Differences between classes in parameter values show preference heterogeneity
  - Class 2 has a stronger than average preference for low costs
  - Class 5 has a weaker preference for low costs

4. Latent Class Model
Summary and Class Descriptions

Class	Description	Explanation	*N*
1	Homebodies	• Strong preference for charging at home	812
2	Economical	• Cost conscious	1,280
3	Impatient	• Strong preference for faster charging	775
4	Environmentally indifferent	• RES share not significant • strongest dislike for charging at work • Technology not significant	291
5	Techies	• Strongest preference for inductive charging • RES share not significant • Weak preference for lower costs • Waiting time not significant • Location not significant	693
6	Ecological	• Strongest preference for green electricity • Waiting time not significant • Location not significant • Technology not significant	246

4. Latent Class Model
Estimation Results 2/3

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Parameters		**Class 1**	**Class 2**	**Class 3**	**Class 4**	**Class 5**	**Class 6**
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Costs: 200 €	-1.91***	-2.19***	-7.01***	-2.47***	-2.07***	-0.20***	-1.46***
Place: at home	(base)	(base)	(base)	(base)	(base)	(base)	(base)
Place: roadside (primary)	-0.65***	-2.41***	-0.65***	-0.47***	-1.29***	-0.07	-0.48
Place: roadside (secondary)	-0.52***	-1.80***	-0.45***	-0.32*	-1.12***	-0.01	-0.40
Place: at work	-0.35***	-0.58***	-0.26	-0.23	-2.60***	-0.02	-0.16
Duration: 10 min	(base)	(base)	(base)	(base)	(base)	(base)	(base)
Duration: 30 min	-0.10***	-0.15**	-0.08	-0.52***	0.15	-0.11**	0.00
Duration: 4 h	-0.55***	-0.80***	-0.71***	-2.24***	-0.43***	-0.10**	-0.35**
Duration: 8 h	-0.96***	-1.32***	-1.30***	-3.87***	-0.72***	-0.20***	-0.81***

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4. Latent Class Model
Estimation Results 3/3

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Parameters	**-**	**Class 1**	**Class 2**	**Class 3**	**Class 4**	**Class 5**	**Class 6**
Tech: tethered	(base)	(base)	(base)	(base)	(base)	(base)	(base)
Tech: inductive	0.11***	0.14***	0.07*	0.22***	-0.13	0.23***	0.09
Wait: 0 min	(base)	(base)	(base)	(base)	(base)	(base)	(base)
Wait: 5 min	0.01	0.02	-0.05	-0.12	-0.12	0.08	-0.15
Wait: 10 min	-0.03	-0.13	-0.20	-0.22	-0.29	0.12	-0.20
Wait: 30 min	-0.25***	-0.68***	-0.47***	-0.73***	-0.63**	0.05	-0.27
Green: 25%	(base)	(base)	(base)	(base)	(base)	(base)	(base)
Green: 50%	0.19***	0.33***	0.32***	0.27***	0.04	-0.00	1.84***
Green: 75%	0.29***	0.39***	0.41***	0.45***	0.06	0.01	3.16***
Green: 100%	0.42***	0.49***	0.61***	0.47***	0.08	0.09	4.63***
Class Probability	-	0.198	0.312	0.189	0.071	0.169	0.060

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4. Latent Class Model
Willingness to Pay: Selected Results

- For a **reduction in charging duration** from 8 hours to 4 hours, people are willing to pay… (in €/month)

	Previous model	Latent Class Model					
Group	**-**	**Class 1** Homebodies	**Class 2** Economical	**Class 3** Impatient	**Class 4** Environ. Indiff.	**Class 5** Techies	**Class 6** Ecological
No. of people	4,097	812	1,280	775	291	693	246
WTP in €/month	33.56	33.07	12.72	106.69	23.72	90.31	51.61

- For an **increase of green electricity** used for charging from 25% to 100%, people are willing to pay… (in €/month)

	Previous model	Latent Class Model					
Group	**-**	**Class 1** Homebodies	**Class 2** Economical	**Class 3** Impatient	**Class 4** Environ. Indiff.	**Class 5** Techies	**Class 6** Ecological
WTP in €/month	34.40	31.73	13.05	30.67	-	-	517.04

Symbol: „-“ Not statistically significant

→Significant differences in preferences between classes: Class *economical* has lowest WTP, *impatient* the highest WTP for faster charging.

5. Conclusions and Future Research

Respondents prefer charging (in order of importance)

- at the lowest costs;
- with shorter charging durations;
- at home to at work to roadside;
- with a higher share of renewable energies;
- with lower waiting times;
- inductively to cable-charging.

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Over the whole range of time intervals, for a reduction of 1 min in

- charging time, consumers are willing to pay 0.15 €/month.
- waiting time, consumers are willing to pay 0.80 €/month.
- Significant preference heterogeneity between classes
- All attributes are significant for the whole sample, but not for all classes

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Further analyze

- different segments (e.g. early adopters, (non-)experts, EV owners)
- Do demographics influence class composition?
- Explore within class heterogeneity with Mixed Logit or Mixed-Mixed Latent Class approach

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References / Related Literature

- Hackbarth, André; Madlener, Reinhard (2013): Consumer preferences for alternative fuel vehicles. A discrete choice analysis. In: *Transportation Research Part D: Transport and Environment* 25, pp. 5–17.
- Hackbarth, André; Madlener, Reinhard (2016): Willingness-to-pay for alternative fuel vehicle characteristics: A stated choice study for Germany. In: *Transportation Research Part A: Policy and Practice* 85, pp. 89–111.
- Hidrue, Michael K.; Parsons, George R.; Kempton, Willett; Gardner, Meryl P. (2011): Willingness to pay for electric vehicles and their attributes. In: *Resource and Energy Economics* 33 (3), pp. 686–705.
- Ito, Nobuyuki; Takeuchi, Kenji; Managi, Shunsuke (2013): Willingness-to-pay for infrastructure investments for alternative fuel vehicles. In: *Transportation Research Part D: Transport and Environment* 18, pp. 1–8.
- Tanaka, Makoto; Ida, Takanori; Murakami, Kayo; Friedman, Lee (2014): Consumers? Willingness to pay for alternative fuel vehicles: A comparative discrete choice analysis between the US and Japan. In: *Transportation Research Part A: Policy and Practice* 70, pp. 194–209.